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The Examination, Testing and Calibration of Portable Radiation Protection Instruments

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National Measurement System

Issue 2

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ABSTRACT

The Ionising Radiation Regulations of 1999 state that all employers undertaking work with ionising radiation must monitor the levels of that radiation within the workplace. This Good Practice Guide describes the recommended procedures for the examination, testing and calibration of portable dose rate and surface contamination monitors that can be used to comply with those statutory obligations.

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Foreword

This Good Practice Guide has been written by the UK Ionising Radiation Metrology Forum* in collaboration with the radiation user community. It describes recommended procedures for the examination, testing and calibration of portable radiation protection instruments. Test procedures recommended in this document are not legally binding: they are general methods based on current accepted good practice.

The current statutory requirement for portable radiation protection instrument tests is stated in the Ionising Radiations Regulations 1999, Regulation 19. All employers who work with ionising radiation must ensure that levels are adequately monitored and instruments are suitable for this purpose.

Although the testing regimes presented here are for general application, Qualified Persons responsible for the calibration of radiation protection instruments may modify them, with the agreement of the Radiation Protection Adviser, as necessary to suit their particular purpose, provided that the employer is satisfied that the overall quality of the testing is not compromised.

* The Ionising Radiation Metrology Forum consists of representatives of UK establishments and organisations involved in radiation measurement for protection purposes. One aim of the forum is to facilitate the exchange of information regarding UK calibration facilities and their efficient use by those required to comply with the regulations.

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FIGURES

1 Introduction

The examination and testing of instruments is a legal requirement for those carrying out work with ionising radiations. The Ionising Radiation Regulations, 1999[1] and their accompanying Approved Code of Practice state that the levels of ionising radiation must be monitored in all designated supervised and controlled areas. The radiation employer shall provide suitable and sufficient equipment for this purpose. The equipment shall be properly maintained and adequately tested and examined at appropriate intervals. While the regulatory responsibilities lie with the employer, it is recognised that, in practice, this individual is unlikely to have sufficient expertise in radiation protection instrumentation to be able to select instruments, define the scope of testing etc. and will take advice from the Radiation Protection Adviser (RPA) and/or qualified person (QP) as appropriate.

This Good Practice Guide provides recommended procedures for the general examination, testing and calibration of portable dose rate and surface contamination monitors. Recommendations made in documents published by national and international organisations, including the United Kingdom Accreditation Service (UKAS), the International Organization for Standardisation (ISO), the International Electrotechnical Commission (IEC) and the International Atomic Energy Agency (IAEA) have been consulted during the preparation of this Guide. Further documents in this guidance series cover the testing of installed monitoring equipment[2], practical radiation monitoring[3], radiometric non-destructive assay[4], uncertainty in radiological measurement[5], testing of airborne radioactive particulate monitors[6], and testing of electronic personal dosemeters[7].

The testing regimes contained herein have no legal standing and employers may implement their own schemes, provided they ensure compliance with the relevant regulations. The procedures described in this guidance are an updated version of those given in the first edition of this document. In its turn, the first edition was derived from the original Health and Safety Guidance (HS(G)49) after revision by the Ionising Radiation Metrology Forum (IRMF). It is the opinion of the IRMF that adoption of the regimes presented in this Guide will normally enable employers to comply with their statutory obligations.

The testing procedures detailed in this guidance provide the minimum level of testing that is recommended for instruments used in normal operating conditions. Users with particularly demanding conditions, such as monitoring for alpha contamination in high gamma dose rates, may well have to go beyond these recommendations and employ

instruments outside the conditions envisaged in the standards above. In such circumstances, the QP and the RPA will need to design appropriate test procedures.

It should be noted that the calibration sources, geometries, etc., specified in this guidance may not correspond to those situations encountered in the workplace. The objective of testing is to demonstrate that the instrument is suitable and fit for use and that its performance agrees with type test data and has not changed significantly since the previous test. Note the emphasis on suitability; it is not sufficient for the instrument to perform correctly: it has to be capable of performing the measurement for which it is being used. Confirmation of agreement with type test data will normally allow the use of 'instrument type' based procedures and reference values without the need to take into account the specific instrument performance. The use of specific sources, geometries, etc., allows users to select from a variety of testing laboratories (including themselves) for the examination, testing and calibration of their instruments, in the knowledge that each is using the same criteria and testing conditions. Comparisons between test results for a particular instrument can therefore be made regardless of the identity of the testing laboratory.

2 Testing regime

IN THIS CHAPTER

- Type tests
- Tests before first use
- Periodic tests
- Analysis of test results

For the purposes of this guidance, a *test* is defined as a procedure to evaluate an instrument's performance in order to establish its suitability, or its continued fitness, for a particular type, or types, of measurement in operational radiation protection. A test may involve an element of *calibration*, which may be defined as the measurement of the response of the instrument to known radiation fields. It is important to recognise that the terms test and calibration are not synonymous: this is because a test will also involve a degree of *examination*, which may include, for example, an inspection of the mechanical and electrical state of the instrument.

Portable radiation protection instruments should undergo Tests Before First Use (TBFU) and subsequently Periodic Tests that are performed under the immediate supervision of a QP at suitable intervals in compliance with current national regulations and associated codes of practice. The findings of these tests must be compared with any previous test information and the appropriate Type Tests to confirm that the instrument is meeting its specification and is suitable for its intended use. The Type Tests are normally carried out by, or on behalf of, the instrument manufacturer. Tests Before First Use and Periodic Tests are generally carried out by, or on behalf of, the employer at a suitable testing laboratory.

It is also considered to be good practice to perform regular Function Checks to ensure an instrument is operating correctly; these are recommended as part of the Health and Safety Executive's guidance to the regulations[1]. Guidance on Function Checking is provided in Appendix 1.

Guidance on the scope of retesting after instrument repairs is available in Appendix 2.

All tests should be traceable and repeatable. A full record of test results, including details of any significant adjustments made to the instrument, should be kept for a minimum period of 2 years.

2.1 Type tests

Before purchasing an instrument, it is the responsibility of the employer to ensure that it is suitable for the intended use. Decisions about instrument selection should be made taking into account advice from the RPA, the QP, information from the manufacturer and other authoritative data that might be available.

The body of information regarding the characteristics and expected performance of instruments is called type test data and is usually based on recommendations from international organisations such as IEC and ISO. However, there are other standards bodies worldwide that produce equally trustworthy and robust guidance on Type Testing. A number of IEC documents exist which detail the tests that are appropriate for the Type Testing of particular types of instrument: some of these IEC documents have been adopted as British and European standards (BS EN) and may differ in detail to the original IEC documents.

The relevant document for testing β and, X and γ dose rate meters is BS EN 60846[8] while BS EN 61005[9] describes the tests required for neutron dose rate meters. BS EN 60325[10] refers to alpha and beta contamination monitors and BS EN 62363[11] relates to photon contamination monitors. Full Type Tests are very comprehensive and may require specialised facilities.

The tests should be performed by someone with appropriate expertise and insight into the use of instruments, in a laboratory with secondary standard or similar status, using measurement quantities specified by the International Commission on Radiation Units and Measurements (ICRU)[12,13] and ISO specified calibration sources and radiation beams[14-21]. There will be circumstances where a user may wish to extend the type test information available, for example, where an instrument is being used in situations beyond the scope of the original Type Test. This is perfectly acceptable provided any extended testing is designed and performed by someone with a sufficient understanding of the instrument, the application for which it will be used and the metrological requirements.

The results of any tests carried out during the lifetime of an instrument should be compared with type test data to ensure that it continues to operate as expected: it is therefore necessary to have access to the type test data for each instrument tested. As a minimum requirement, the type test data should include results of tests equivalent to those defined in the TBFU for a particular instrument type: these tests are listed in Table 1.

For most new instruments, the manufacturers or suppliers provide type test data that will enable the employer to decide the necessary scope of TBFU. In the absence of independent or manufacturer's type test data, other sources of information, for example published peer-reviewed evaluations, may be useful. When type test data are not available, or are deemed insufficient, in the judgement of the QP and RPA, sufficient tests should be performed at the TBFU stage to establish baseline data.

2.2 Tests before first use

Assuming that the instrument is delivered in good condition and set up according to its specifications, the TBFU should demonstrate that the instrument conforms to type and confirm its suitability for the intended use. The tests should check for any potential faults and identify any limitations of the instrument with respect to its intended use. The tests may be undertaken by the manufacturer, the employer or an independent laboratory.

Table 1 summarises the tests required for the TBFU of dose rate and surface contamination monitors. The recommended procedures for each of the tests are provided in Section 4. Some of these tests may need to be repeated periodically as the performance of an instrument can vary with age, key components may deteriorate or fail, and damage may occur during use: these are some of the reasons for the subsequent Periodic Tests. After any repair that could affect the performance of the instrument, it may be necessary to repeat some of the TBFU (Appendix 2 provides guidance on the scope of such testing).

2.3 Periodic tests

It is the responsibility of the employer to define the frequency of Periodic Tests based upon considerations such as the age of the equipment, the environment in which it is used, and the frequency of use. It is the recommendation of the Approved Code of Practice[1] that examination and testing be performed at least annually; however, it may be appropriate to test instruments more frequently if they are used in challenging conditions. The requirements of any future regulations must be adhered to.

The purpose of Periodic Testing is to check that the instrument remains fit for use and to confirm that its performance has not changed significantly since the TBFU. Although it is more than just a simple check, highly specialised facilities are not necessarily required for Periodic Testing: the facilities should be suitable to allow measurements to be made to a known and sufficient accuracy.

The tests required for the Periodic Tests are summarised in Table 1 and are broadly similar to those for the TBFU. Specific details of the tests are provided in Section 4.

Since an instrument may suffer from wear and tear or misuse during its lifetime, attention should be paid to the performance and condition of its electrical and mechanical systems. For example, desiccators, batteries, cables, connectors, controls and any zero setting should be examined and any necessary repairs or adjustments carried out before the radiation response of the instrument is tested. Appendix 2 discusses the depth of testing after repairs.

It is recommended, for conventional instruments, that probes are not routinely exchanged between ratemeters and that the probe and ratemeter combination is tested as an assembly. Interchanging probes and ratemeters brings a significant risk of confusion and should be avoided except when demanded by operational constraints.

In cases where probes and ratemeters are interchanged in the workplace, the user must be able to confirm that each component and any cabling are not defective and remain fit for use. This means that both the probe and ratemeter must have undergone a TBFU or a Periodic Test, before the combination is used operationally. A suitable check should be devised to ensure that the results of the TBFU or previous Periodic Tests have not been invalidated by changing the combination of probe and ratemeter: such a check will be specific to the probe and ratemeter but measurement of the background indication and of the response to a check source (with an energy close to the minimum intended energy of use) are often appropriate.

For instruments which employ intelligent probes, i.e. those where the probe rather than the ratemeter defines the operating parameters, exchange of probes and ratemeters will normally be acceptable but checks of background indication and the response to a check source (with an energy close to the minimum intended energy of use) are still recommended. Note that for these probes the manufacturer should be asked to demonstrate the validity of this exchange process; this reduced level of testing is only acceptable when a written statement of the validity has been provided.

For neutron monitors, it is not practical to perform a low energy test during periodic testing since suitable sources are not generally available.

2.4 Analysis of test results

The results of the TBFU should be compared with the type test data, and, the Periodic Tests of an instrument should be compared with the results of previous Periodic Tests, TBFU and type test data to confirm that the instrument still conforms to type and remains fit for use.

The employer should keep a full record of test results, including details of any significant adjustments made to the instrument. Current test results should be

compared with previous results and any significant changes or trends noted and investigated, even if all the results fall within specification. For example, the performance of an instrument should be regarded as suspicious if a gradual deterioration of response is observed, in which case the cause of the drift should be investigated by the Qualified Person and corrective actions taken.

Whenever an instrument is adjusted during the course of testing, a statement indicating the nature and magnitude of the adjustment should be made on the test report or calibration certificate. Furthermore, details of the instrument response before and after adjustment should be reported.

An instrument may fail the TBFU or Periodic Tests if the results of any component of the appropriate tests are not within the acceptable limits defined in Tables 2 to 8, or if the instrument's performance is deemed unsatisfactory by the QP. If an instrument does fail a TBFU or Periodic Test, the testing laboratory should inform the customer or instrument user of the nature of the problem. It is then the responsibility of the instrument user's RPA to decide if the results of monitoring previously performed using the instrument should be investigated and corrective actions taken. The customer should decide whether the instrument should be repaired or replaced.

Table 1: Summary of tests before first use and periodic tests

INSTRUMENT USE	TESTS BEFORE FIRST USE	PERIODIC TESTS
Photon dose rate	Response to High Dose Rates Linearity Background Indication Light Leakage Energy Dependence Directional Dependence	Response to High Dose Rates Linearity Background Indication Light Leakage Energy Dependence
Beta dose rate	Response to High Dose Rates Linearity β Response Background Indication	Response to High Dose Rates Linearity β Response Background Indication
Neutron dose rate	Response to High Dose Rates Linearity γ Rejection Background Indication Directional Dependence	Response to High Dose Rates Linearity γ Rejection Background Indication
Alpha contamination	Light leakage Response to α contamination Linearity β rejection Background count rate Uniformity of response	Light leakage Response to α contamination Linearity β rejection Background count rate
Beta contamination	Light leakage Response to β contamination Linearity Background count rate Uniformity of response	Light leakage Response to β contamination Linearity Background count rate
Dual alpha and beta contamination	Light leakage Response to α contamination Response to β contamination Alpha channel linearity Beta channel linearity β rejection in alpha channel Background count rate in α channel Background count rate in β channel Uniformity of alpha response Uniformity of beta response	Light leakage Response to α contamination Response to β contamination Alpha channel linearity Beta channel linearity β rejection in alpha channel Background count rate in α channel Background count rate in β channel
Photon contamination	Light leakage Response to photon contamination Linearity Background count rate Uniformity of response	Light leakage Response to photon contamination Linearity Background count rate

3 Instruments

IN THIS CHAPTER

- Photon (x and γ) dose rate meters
- Beta (β) dose rate meters
- Neutron dose rate meters
- Alpha (α) contamination monitors
- Beta (β) contamination monitors
- Dual alpha (α) and beta (β) contamination monitors
- Photon (x and γ) contamination monitors

The type, nature and intensity of radiation that an instrument may encounter, and the conditions under which it may be used, should be considered when selecting an instrument. The employer should seek advice from their RPA and QP when instrument selection is made: the published literature may also be consulted[3, 22].

Radiation protection instruments can have a variety of readout modes, for example, dose rate or integrated dose, analogue or digital, and even a pulse output mode indicating the detection of individual photons, neutrons, etc. Unless all tests are to be performed in all output modes, the particular mode normally employed should be confirmed with the instrument user and adopted for the tests: a statement of the readout mode tested should be made on the calibration certificate or test report.

3.1 Photon (x and γ) dose rate meters

Instruments for the measurement of photon dose rates are manufactured with a variety of detectors including ionisation chambers, Geiger-Müller tubes, proportional counters and a variety of scintillation detectors including plastic and sodium iodide. The tests required to establish the linearity, energy dependence, directional dependence and other relevant characteristics of these meters are detailed in Section 4. Table 2 is a quick reference guide for these meters and provides a brief description of each of the tests. Further information regarding photon dose rate tests is given in Appendix 3.

3.2 Beta (β) dose rate meters

Beta dose rate instruments use a variety of detectors, including thin-window ionisation chambers, end-window Geiger-Müller tubes, proportional counters and scintillation detectors. An outline of the tests for β dose rate meters is given in Table 3 and more information is provided in Section 4.

Many β dose rate meters will also be used for X and γ dose rate monitoring. For convenience in such cases, the measurement of β response should be made after the

photon dose rate tests have been completed. For those instruments that are used purely to monitor β dose rates, the response at high dose rates and instrument linearity should be investigated before confirming the β dose rate response.

3.3 Neutron dose rate meters

Instruments for measuring neutron dose rate conventionally consist of a thermal neutron sensor at the centre of a polyethylene moderating sphere or cylinder. The central sensor can be a proportional or scintillation counter, or even an ionisation chamber. Newer devices based, for example, on microdosimetric counters or scintillation combinations are also available.

Although the procedures are basically similar, the testing of neutron dose rate meters is a more specialised operation than that required for β or photon dose rate meters. The main difference between them is the scattering properties of neutrons, which means that special techniques and corrections are necessary during tests: for neutrons, specially designed low scatter facilities are often necessary. Table 4 contains a summary of tests for neutron meters and Section 4 and Appendix 4 provide further information on neutron dose rate tests.

3.4 Alpha (α) contamination monitors

These instruments normally have scintillation detectors, proportional counters or solid state detectors. Tests of α contamination monitors include a measurement of the response to a large area α source, measurement of instrument linearity, checks on β rejection characteristics, uniformity of response over the detector area, observed background count rate and checks to identify any light leakage (for scintillation and solid state counters mainly). A brief description of these tests is provided in Table 5 while detailed information can be found in Section 4.

3.5 Beta (β) contamination monitors

Instruments used to measure β contamination in the workplace have detectors in three main categories: end-window and thin-walled Geiger-Müller detectors; proportional counters; and scintillation counters. The tests required for these instruments include checks on their response to β contamination of an energy at or below the minimum energy to be monitored in the workplace, uniformity of response over the detector area, the observed background count rate and a check to identify any light leakage (for scintillation and solid state detectors mainly).
Table 6 outlines tests for β contamination monitors and further details can be found in Section 4.

3.6 Dual alpha (α) and beta (β) contamination monitors

Some instruments are designed to respond to, and discriminate between, alpha and beta contamination. These instruments display alpha and beta count rates in separate

channels. A fundamental feature of these instruments is that the contribution of beta radiation to the alpha channel should be negligible and the performance should meet the pass/fail criteria given for alpha monitors (see Table 5 and Section 4.7). Correct setting of the operating point is even more important for dual probes than for separate alpha and beta probes.

Tests required for dual alpha and beta monitors include response to a large area α source, measurement of alpha channel linearity, checks on alpha channel β rejection characteristics, checks on the response to β contamination and beta channel linearity. Table 7 contains a summary of tests for dual α and β probes and further information is available in Section 4.

3.7 Photon (x and γ) contamination monitors

Many photon emitting radionuclides also emit α or β particles: in these cases, contamination monitoring normally makes use of the particulate emissions rather than the photons. For pure photon emitting radionuclides, or where the α or β component is severely attenuated, the photon emissions may be employed.

Instruments used to measure contamination from photon emitting radionuclides in the workplace usually have proportional counters or scintillation detectors. The tests required for these instruments are the response to photon contamination over the energy range likely to be encountered in the workplace, linearity of response, uniformity of response, response to normal background radiation and a test for possible light leakage (for scintillation and solid state detectors mainly). The tests for photon contamination monitors are summarised in Table 8.

Table 2: Tests required for photon dose rate meters

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
RESPONSE TO HIGH DOSE RATES Expose the instrument to a dose rate in excess of that which it could reasonably encounter in practice, for at least thirty seconds. A minimum dose rate of 10 $mSvh^{-1}$ should be used.	Do not test instruments that are designed to measure very low dose rates and are likely to be damaged by this process. The background indication from some scintillators may be increased after testing and take up to a day to return to the original value.	If the high dose rate used is above the range of the instrument, the overload indication should operate for the duration of the test. The instrument performance should return to normal after the test.	Yes	Yes	Section 4.1
LINEARITY Mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Ensure secondary electron equilibrium. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace.	^{60}Co may be used if convenient.	Agreement to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.2
ENERGY DEPENDENCE Mount the instrument in the calibration orientation, with its reference point at the point of test in the radiation field of a 60 keV (^{241}Am) photon source. The dose rate from the 60 keV source should be adjusted until the instrument reading is close to one of those obtained for ^{137}Cs in the linearity test. Determine the instrument's response to the 60 keV source.	Filtered X-radiation from the ISO low or narrow series[15] may also be used, particularly for high dose rate detectors. If the instrument is used to monitor photons of energy less than 60 keV, a test at a lower energy is necessary.	The ratio of the 60 keV response to the ^{137}Cs or ^{60}Co response (from the linearity test) should agree within ± 30 % of that in type test data.	Yes	Yes	Section 4.3 & Appendix 3.5
DIRECTIONAL DEPENDENCE Mount the instrument and determine its response to a 60 keV source as in the energy dependence test. Rotate the instrument and determine its response at + 90° and - 90° in an appropriate plane about its calibration point. Some instruments have a very low response for 60 keV radiation at 90°. In such cases, a test at 60° may be used. The Type Test should provide appropriate information.	A test in the other plane of the instrument may also be necessary. For high dose rate detectors it may be necessary to use filtered X-radiation. All detectors should be tested.	Responses should agree to within ± 30 % of those obtained in Type Tests.	Yes	No	Section 4.4
BACKGROUND INDICATION The background indication should be checked in an area known to have a low, stable background dose rate.		Observed background indication should be comparable with that stated by manufacturer, taking into account local background conditions.	Yes	Yes	Section 4.5
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe the background indication.	Generally necessary for scintillation and solid state detectors but some end-window Geiger-Müller tubes are also susceptible.	Background indication should not be affected.	Yes	Yes	Section 4.8

Table 3: Tests required for beta dose rate meters

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
RESPONSE TO HIGH DOSE RATES Expose the instrument to a dose rate in excess of that which it could reasonably encounter in practice, for at least thirty seconds. A minimum dose rate of 10 mSv h^{-1} should be used. A beta source should be used to test instruments which do not detect, or are designed to compensate for, photons.	Do not test instruments that are designed to measure very low dose rates and are likely to be damaged by this process. The background indication from some scintillators may be increased after testing and take up to a day to return to the original value.	If the high dose rate used is above the range of the instrument, the overload indication should operate for the duration of the test. The instrument performance should return to normal after the test.	Yes	Yes	Section 4.1
LINEARITY Mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace. The linearity of an instrument can also be determined using a set of β sources of different emission rates but of the same radionuclide and construction.	This test should be performed before confirmation of the β response. ^{60}Co may be used if convenient.	Agreement in instrument responses to within ± 30 % of manufacturer's specified performance. Each of the instrument responses should agree to within ± 30 % of the mean of all three responses.	Yes Yes	Yes Yes	Section 4.2 Section 4.10
CONFIRMATION OF β RESPONSE If sources are available, the instrument's response to a set of secondary standard β dose rate sources should be measured (^{147}Pm, ^{204}Tl (or ^{85}Kr), and $^{90}Sr + ^{90}Y$). Testing using a low energy large area beta contamination source is an acceptable alternative: the most appropriate radionuclide is ^{14}C.	Beta secondary standard sources are not commonly available. In their absence, the manufacturer should be asked to supply data on the response of the instrument to large area beta contamination sources.	Agreement to within ± 30 % of type test data.	Yes	Yes	Section 4.6
BACKGROUND INDICATION The background indication should be checked in an area known to have a low, stable background dose rate.		Observed background indication should be comparable with that stated by manufacturers.	Yes	Yes	Section 4.5
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe the background indication.	Generally necessary for scintillation and solid state detectors but some end-window Geiger-Müller tubes are also susceptible.	Background indication should not be affected.	Yes	Yes	Section 4.8

Table 4: Tests required for neutron dose rate meters

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
RESPONSE TO HIGH DOSE RATES Expose the instrument to a dose rate in excess of that which it could reasonably encounter in practice, for at least thirty seconds.	Do not test instruments that are designed to measure very low dose rates and are likely to be damaged by this process.	If the high dose rate used is above the range of the instrument, the overload indication should operate for the duration of the test. The instrument performance should return to normal after the test.	Yes	Yes	Section 4.1
LINEARITY Mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of an ^{241}Am-Be, ^{252}Cf or an accelerator produced source of neutrons. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace.	Scatter corrections will be necessary.	Agreement to within ± 30 % of manufacturer's specified performance	Yes	Yes	Section 4.2
ENERGY DEPENDENCE Since it is difficult to confirm a neutron instrument's energy dependence, this test is not generally performed.	A detailed explanation can be found in Appendix 4.5.		No	No	Section 4.3 & Appendix 4.5
DIRECTIONAL DEPENDENCE Mount the instrument and determine its response to an ^{241}Am-Be, ^{252}Cf or an accelerator produced source of neutrons as in the linearity test. Rotate the instrument and determine its response at + 90° and then - 90° in an appropriate plane about its calibration point.	A test in the other plane of the instrument may also be necessary. All detectors should be tested.	Responses should agree to within ± 30 % of those obtained in Type Tests.	Yes	No	Section 4.4
γ REJECTION Expose the instrument to a suitable ^{137}Cs or ^{60}Co source.		Response should not be greater than 1.5 times that obtained in Type Tests.	Yes	Yes	Section 4.7
BACKGROUND INDICATION The background indication should be checked in an area known to have a low, stable background dose rate.		Observed background indication should be comparable with that stated by manufacturers.	Yes	Yes	Section 4.5

Table 5: Tests required for alpha contamination monitors

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe any change in response. Check the instrument response to a small α source, with and without the presence of the light source.	Generally necessary for scintillation and solid state detectors but some end-window Geiger-Müller tubes are also susceptible.	Background count rate should not be elevated and the response to the α source should not be affected by the presence of the light.	Yes	Yes	Section 4.8
RESPONSE TO α CONTAMINATION Mount the detector parallel to, and 3 mm above, a source of dimensions as least as large as the detector and determine its response. If the detector is larger than available sources, perform a contiguous portions test.	Use a range of calibration sources to reflect the energies encountered in the workplace.	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.9
LINEARITY Determine the instrument's response to a series of α point sources of known emission rate: ^{241}Am is usually suitable. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three sources should be used.	A jig may be used to ensure source and detector positions are reproducible.	Each of the instrument responses should agree to within ± 30 % of the mean of all three responses.	Yes	Yes	Section 4.10
UNIFORMITY OF RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm^2 area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm^2 need be tested.	No more than 30 % of the total detector area should have a response which is less than 30 % of the mean response for the whole detector.	Yes	No	Section 4.11
β REJECTION Place the instrument 3 mm from a ^{90}Sr + ^{90}Y source and determine its response.	For use in areas of high gamma dose rate, a check on gamma rejection is also recommended.	Observed response to the β source should be less than 1 % of the instrument's response to an alpha source of similar emission rate.	Yes	Yes	Section 4.7
BACKGROUND COUNT RATE Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes	Section 4.5

Table 6: Tests required for beta contamination monitors

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERI	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe any change in response.	Generally necessary for scintillation and solid state detectors but some end-window Geiger-Müller tubes are also susceptible.	Background count rate should not be affected.	Yes	Yes	Section 4.8
RESPONSE TO β CONTAMINATION Mount the detector parallel to, and 3 mm above, a source of dimensions as least as large as the detector and determine its response. If the detector is larger than available sources, or if medium or high energy betas are being measured, perform a contiguous portions test.	Use a range of calibration sources to reflect the energies encountered in the workplace. The lowest energy source should have an energy at or below that of the minimum to be monitored: ^{14}C is recommended for all wide energy range detectors.	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.9
LINEARITY Determine the instrument's response to a series of β point sources of known emission rate: ^{90}Sr is usually suitable. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three sources should be used.	A jig may be used to ensure source and detector positions are reproducible.	Each of the instrument responses should agree to within ± 30 % of the mean of all three responses.	Yes	Yes	Section 4.10
Alternatively, mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace.	^{60}Co may be used if convenient.	Agreement to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.2
UNIFORMITY OF RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm^2 area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm^2 need be tested. The energy of the source used should be equal to or less than the minimum energy to be monitored in the workplace.	No more than 30 % of the total detector area should have a response which is less than 30 % of the mean response for the whole detector.	Yes	No	Section 4.11
BACKGROUND COUNT RATE Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes	Section 4.5

Table 7: Tests required for dual alpha and beta contamination monitors

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe any change in response. Check the instrument response to a small α source, with and without the presence of the light source.	Generally necessary for scintillation and solid state detectors only.	Background count rate should not be affected.	Yes	Yes	Section 4.8
RESPONSE TO α CONTAMINATION Mount the detector parallel to, and 3 mm above, a source of dimensions as least as large as the detector and determine its response. If the detector is larger than available sources, perform a contiguous portions test.	Use a range of calibration sources to reflect the energies encountered in the workplace.	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.9
RESPONSE TO β CONTAMINATION Mount the detector parallel to, and 3 mm above, a source of dimensions as least as large as the detector and determine its response. If the detector is larger than available sources, or if medium or high energy betas are being measured, perform a contiguous portions test.	Use a range of calibration sources to reflect the energies encountered in the workplace. The lowest energy source should have an energy at or below that of the minimum to be monitored: ^{14}C is recommended for all wide energy range detectors.	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.9
ALPHA CHANNEL LINEARITY Determine the instrument's response to a series of α point sources of known emission rate: ^{241}Am is usually suitable. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three sources should be used.	A jig may be used to ensure source and detector positions are reproducible.	Each of the instrument responses should agree to within ± 30 % of the mean of all three responses.	Yes	Yes	Section 4.10
BETA CHANNEL LINEARITY Determine the instrument's response to a series of β point sources of known emission rate: ^{90}Sr is usually suitable. Sources should be chosen to span the range of count rates that the instrument may be expected to measure. At least three sources should be used. Alternatively, mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace.	A jig may be used to ensure source and detector positions are reproducible. ^{60}Co may be used if convenient.	Each of the instrument responses should agree to within ± 30 % of the mean of all three responses. Agreement to within ± 30 % of type test data.	Yes Yes	Yes Yes	Section 4.10 Section 4.2
UNIFORMITY OF ALPHA RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm^2 area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm^2 need be tested.	No more than 30 % of the total detector area should have a response which is less than 30 % of the mean response for the whole detector.	Yes	No	Section 4.11

UNIFORMITY OF BETA RESPONSE Use one of the point sources from the linearity tests to determine the instrument response for each 10 cm^2 area of the detector window. Calculate the mean response over the whole window.	Only instruments with detector areas in excess of 40 cm^2 need be tested.	No more than 30 % of the total detector area should have a response which is less than 30 % of the mean response for the whole detector.	Yes	No	Section 4.11
β REJECTION IN ALPHA CHANNEL Place the instrument 3 mm from a $^{90}Sr + ^{90}Y$ source and determine its response.	For use in areas of high gamma dose rate, a check on gamma rejection is also recommended.	Observed response to the β source should be less than 1 % of the instrument's response to an alpha source of similar emission rate.	Yes	Yes	Section 4.7
BACKGROUND COUNT RATE IN ALPHA CHANNEL Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes	Section 4.5
BACKGROUND COUNT RATE IN BETA CHANNEL Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturers.	Yes	Yes	Section 4.5

Table 8: Tests required for photon contamination monitors

TEST REQUIRED	COMMENTS	PASS/FAIL CRITERIA	TESTS BEFORE FIRST USE	PERIODIC TESTS	DETAILED REFERENCE
LIGHT LEAKAGE Expose the instrument to an appropriate light source and observe any change in response.	Generally necessary for scintillation and solid state detectors but some end-window Geiger-Müller tubes are also susceptible.	Background count rate should not be affected.	Yes	Yes	Section 4.8
RESPONSE TO PHOTON CONTAMINATION If a standard calibration is appropriate, determine the instrument response with a source - detector separation of 3 mm. Alternatively, particularly for instruments intended for energetic gamma emitters, determine the response using point or dosimetric gamma sources.	Use a range of calibration sources to reflect the energies encountered in the workplace. The lowest energy source should have an energy at or below that of the minimum to be monitored. Reproduce the type test geometry or method once then establish a reference geometry or method for future calibrations.	Responses should agree to within ± 30 % of manufacturer's specified performance.	Yes	Yes	Section 4.9
LINEARITY Mount the instrument in the calibration orientation with its reference point at the point of test in the radiation field of a ^{137}Cs source. Measure the instrument's response to the field for each range or decade of the instrument, up to the maximum dose rate it could reasonably encounter in the workplace. Ensure secondary electron equilibrium. If the detector responds reliably to beta radiation, it is acceptable to use a set of beta emitting sources.	Other radionuclides may be used if convenient.	Agreement to within ± 30 % of type test data.	Yes	Yes	Section 4.10
UNIFORMITY OF RESPONSE Determine the instrument response for each 10 cm^2 area of the detector window when it is exposed to a suitable source (see comments). Calculate the mean response over the whole window.	For highly penetrating radiations, it is not easy to determine detector uniformity, as effectively masking the majority of the detector area from those radiations is difficult. A photon source of energy similar to the minimum used in the workplace should be used.	No more than 30 % of the total detector area should have an instrument response which is less than 30 % of the mean response for the whole detector.	Yes	No	Section 4.11
BACKGROUND COUNT RATE Measure the background count rate in an area of known low background.	If the background is elevated, the instrument may be contaminated.	Observed background count rate should be comparable with that stated by the manufacturer.	Yes	Yes	Section 4.5

4 Specific Tests

IN THIS CHAPTER

- Response of dose rate meters to high dose rates
- Linearity of response of dose rate meters
- Energy dependence of dose rate meters
- Directional dependence of dose rate meters
- Background indication of dose rate meters
- Confirmation of β response for β dose rate meters
- Rejection characteristics
- Light leakage
- Response to contamination
- Linearity of response of contamination monitors
- Uniformity of response of contamination monitors
- Testing for use in unusual circumstances

Table 1 lists the tests that are applicable to the TBFU and the Periodic Tests for all instrument types covered in this Guide. Tables 2 to 8 cover the tests required for particular types of instrument and provide brief summaries of the tests and their pass/fail criteria. However, the tables are not comprehensive and should not be used without reference to the detailed information in this Section. The tests do not have to be performed in the order in which they are listed in the tables and may be undertaken in an order which is convenient to the testing laboratory. If the Response to High Dose Rates of dose rate meters is not tested first, it is important to check that exposure to the high dose rate has not adversely affected the instrument.

Since many of the tests required for one instrument type are similar to those for another, general procedures for each of the tests have been provided. Where there are deviations from the general procedure, special requirements for a particular type of instrument or additional information, they have been detailed beneath the test.

4.1 Response of Dose Rate Meters to High Dose Rates

In the workplace, failure of equipment or operational procedure could lead to dose rates far beyond those routinely encountered. This possibility should have been recognised in a risk assessment and an instrument selected that has been type tested to a sufficiently high dose rate.

If it is possible, an instrument should be tested up to at least the maximum dose rate it could potentially encounter. However, this may not always be practicable: in such a case, the instrument should be tested to as high a dose rate as practicable and then an

analysis of the instrument function undertaken to confirm that there is no reasonable possibility of it failing to danger in the event of extremely high dose rates being encountered. This requires a detailed understanding of how the instrument operates, in particular the detector, polarising supply and input amplifier. The QP responsible for the tests may consult the RPA, the manufacturer and the National Physical Laboratory for specialist advice.

For instruments that are unlikely to encounter high dose rates, a test at high dose rates is still recommended and they should be checked at a level of at least 10 mSv h^{-1}. A large uncertainty (± 50 %) in the dose rate in the calibration field is acceptable when only the response to high dose rates is being checked.

To perform the response to high dose rate test, the instrument should be exposes to the selected high dose rate for at least 30 seconds and its indication observed. The high dose rate used for this test should be indicated on the certificate or test report. If the response to high dose rates is tested after the measurement of instrument linearity, the response should be rechecked at a low dose rate to ensure that the high dose rate test has not damaged the instrument.

If the high dose rate used for this test is greater than the maximum indication of an instrument, its overload function should operate clearly. For instruments with conventional analogue meters, the needle should go off scale beyond the maximum indication and stay there for the duration of the test, which should last for at least thirty seconds. For instruments with liquid crystal or similar displays, the overload indication should operate clearly. For autoranging instruments which use two detectors, a sensitive detector for low dose rates and a relatively insensitive detector for high dose rates, the linearity measurement at high dose rates will effectively operate as an overload test for the sensitive detector. Care should be taken to ensure that both detectors are irradiated, because such instruments normally compare count rates from the two detectors. Shielding of the low dose rate detector may result in the instrument oscillating between two detectors as both may be producing count rates within their operating ranges.

If the high dose rate used for this test is insufficient to force an instrument into overload, i.e. if the dose rate corresponds to an instrument indication that is less than the maximum possible, the instrument response at this dose rate should be recorded on the certificate or test report.

The background indication from some scintillators may be increased after testing and take up to a day to return to the original value.

Beta dose rate meters that do not detect photons, or are designed to compensate for photon radiations, should be tested using a β source of sufficient activity. The separation between the source and detector can be quite small, provided the dose rate at the position of the effective detector centre can be estimated to within ± 50 %.

For neutron dose rate instruments, requirements to carry out tests at high dose rates could create special problems and, in contrast to photon radiations, it is not a straight-forward matter to obtain dose rates of 10 mSv h^{-1}. Unless it is possible for such high dose rates to be present in the workplace, a less restrictive Periodic Test can be used, subject to a satisfactory Type Test and TBFU of the overload response of the instrument. A 37 GBq ^{241}Am-Be source, positioned at 0.25 m from the centre of a neutron dose rate instrument with a moderating sphere, should give a dose rate approaching 400 μSv h^{-1}; this will be a sufficiently high dose rate for the majority of applications.

The high dose rate test need not be applied to instruments that are not used for the purpose of the regulations[1] (as they are beyond the remit of this document). Examples of such instruments include those intended to measure environmental γ dose rates and those used to detect low level leakage from high voltage cathode ray tubes. Organically quenched Geiger-Müller detectors should not be tested as they have a limited life that can be used up rapidly during high dose rate testing. Accordingly, these detectors should not be used where there is significant chance of a dose rate or count rate in excess of the maximum value that was used during testing.

4.2 Linearity of response of dose rate meters

Appendix 3 accompanies this Section and provides advice on suitable methods for source and instrument positioning, beam collimation and techniques for the variation of dose rates.

The linearity test is suitable for X and γ dose rate meters and neutron dose rate meters: it can also be used for β dose rate meters that are also suitable for photon dose rate monitoring (an alternative test for β dose rate meters is provided later in this Section). If this test is used for β dose rate meters, it is recommended that the photon dose rate tests are performed before confirmation of the β response. This test is also suitable for some β and photon contamination monitors.

Most instruments used for measuring dose rates will be scaled in dosimetric units but some may be scaled in counts per second or counts per minute. These instruments should be tested in exactly the same way and the results compared with type test data. The response of most photon dose rate meters is normalised to ^{137}Cs gamma radiation.

However, there are some types, mainly designed for low energy use, where the ratio of the instrument response to the delivered dose rate is not unity. It is also important to recognise that wide range instruments may have significant deviations from unity at high dose rate levels because of limitations in the dead-time correction. The assessment of an instrument's performance must take these deviations into account.

The recommended radiation sources for photon and β dose rate meters are ^{137}Cs, or ^{60}Co if more convenient; X rays can also be used to extend the range of dose rates available for testing if necessary. For neutron meters, ^{241}Am-Be or ^{252}Cf sources or accelerator produced neutrons of an appropriate energy can be used. Reference gamma-ray sources (^{137}Cs and ^{60}Co), and radionuclide neutron sources (^{241}Am-Be and ^{252}Cf) are available commercially and can be calibrated at national measurement institutes.

If the instrument linearity is tested with a radionuclide different to that used in Type Testing, a correction should be applied to account for the difference in response with energy. For example, a typical ^{60}Co/^{137}Cs response ratio derived from the Type Test for an energy compensated Geiger-Müller detector is 1.25; applying this factor will allow the results derived from ^{60}Co measurements to be compared directly with the type test linearity for ^{137}Cs.

The instrument under test should be mounted in the calibration orientation with its reference point (marked calibration point on the instrument) at the point of test in the radiation field. In the absence of a marked calibration point, or information in the manufacturer's literature about the position of the reference point, the geometric centre of the detector should be used; this may require opening the instrument.

For photon instruments, secondary electron equilibrium should be assured. Secondary electron equilibrium is automatic for instruments with thick walls, such as energy compensated Geiger-Müller types. For ionisation chamber instruments, measurements should be performed with the slide closed or end cap in place. Any instruments with thin walls or windows between the active volume and the source, for example, thin end-window Geiger-Müller detectors, should have a plastic cap at least 3 mm thick added for testing using ^{137}Cs gamma radiation and a 10 mm cap for ^{60}Co.

The instrument's response to the field should be measured for at least one dose rate in each range or decade of the instrument, up to the maximum dose rate that it could reasonably encounter in the workplace, even under accident conditions: for neutron meters this will require suitable corrections to be made for the effects of scattering. If the response of an instrument is found to be unsatisfactory, it may be possible for it to

be adjusted or repaired to give an acceptable response over its range of use. Any adjustment made should be reported on the certificate or test report.

For digital instruments with stored count rate or dose rate correction factors, it may be sufficient to make measurements at high and low dose rate points for each detector. It is important that the design of the instrument is checked by the QP to ensure that this is a valid method and that there are no mechanisms for the instrument to deviate significantly from specification without it being manifested at either or both points. It is recommended that a written statement of the validity of this method is obtained from the instrument manufacturer.

The indication on the instrument may fluctuate significantly, particularly at low dose rates, so sufficient readings should be taken to establish a mean indication with suitable accuracy (± 10 % standard deviation of the mean), or eye average the reading for a minimum of two time constants.

For β dose rate instruments, the linearity can also be established using a set of standard β sources of the same radionuclide and construction but of different emission rates. A suitable general method for this test is given in Section 4.10. Note that for ionisation chambers, positioning the source very close to the detector end window produces a very intense dose rate near the source; this may lead to poorer apparent dose rate linearity than would result from a more distant source irradiating the detector more uniformly. It is possible to correct the indication of an ionisation chamber tested in this way by comparing it with the indication from a transfer standard, in the same geometry, that has been tested conventionally using photon sources as described earlier in this Section and applying a correction.

Where appropriate, the test certificate should give the instrument response, or calibration factors which enable the user to convert the instrument indication to dose rate, or quote that the instrument's response is acceptable within a specified range of dose rates, or that it has been adjusted to be acceptable within the range. The instrument responses in the known calibration fields should be within ± 30 % of the manufacturer's reference values. Any untested ranges or decades should be clearly indicated on the test report or calibration certificate.

4.3 Energy dependence of dose rate meters

This test is necessary in the TBFU and is recommended for the Periodic Tests for photon dose rate monitors. The energy dependence test for β dose rate meters is covered in Section 4.6.

The energy dependence of instruments used to measure photon dose rates in the workplace is governed by the type of detector and, in some cases, on the set-up of the instrument. The test is designed to confirm that the response of the instrument does not vary with energy in a manner which is significantly different to that quoted in the type test data. The test utilises the information obtained in the linearity test and combines it with a test procedure using an ^{241}Am photon source. This test should identify any major faults in the detector for most instrument designs.

Information at one energy (corresponding to ^{137}Cs or ^{60}Co) should have been obtained in the linearity test described in Section 4.2. For many instruments, a test at a much lower energy is required to confirm that the energy dependence corresponds, within acceptable limits, to that quoted in type test data. This is because misassembly or the use of wrong materials during repair may have a negligible effect on instrument response at high energies, while having a more significant effect at low energies. Typical examples include the incorrect assembly of an energy-compensated Geiger-Müller detector or the use of the wrong grade of conductive coating in an ionisation chamber.

The instrument under test should be mounted in the calibration orientation with its reference point (marked calibration point on the instrument) at the point of test in the radiation field. In the absence of a marked calibration point or information in the manufacturer's literature about the position of the reference point, the geometric centre of the detector should be used; this may require opening the instrument.

For general use instruments that are intended for low dose rates, the recommended radiation energy is 60 keV (^{241}Am γ radiation), although an appropriate X radiation quality from the ISO low or narrow series of reference filtered X radiation can be used[14-16]. The dose rate from the ^{241}Am source or X radiation should be adjusted until the instrument indication is close to one of those from ^{137}Cs or ^{60}Co used in the linearity measurement, so as to eliminate any effects of non-linearity. The true dose rate, at the point of test in the ^{241}Am or X radiation field, should then be determined and the instrument response or calibration factor derived.

For instruments which are intended for emergency use, a much less sensitive detector is fitted, either singly or in combination with a low dose rate detector. With these, it is difficult to use ^{241}Am as a low energy reference gamma radiation as available dose rates are too low and, often, the detector response declines rapidly below 80 keV. Testing these instruments requires an X ray set generating an appropriate filtered quality, generally with a tube potential of 100 kV.

The ratio of the 60 keV or low energy X ray response to that for ^{137}Cs or ^{60}Co γ radiation should be calculated and compared with type test data. The ratios obtained should agree with the type test data to within ± 30 %. Caution should be exercised when comparing an ^{241}Am 60 keV to ^{137}Cs response ratio with an X ray 60 keV to ^{137}Cs ratio, due to the fact that the X radiation is emitted with a range of energies while the 60 keV emission from ^{241}Am is monoenergetic; as a consequence the instrument's response is unlikely to be identical for the two radiations.

Each detector of an instrument should be checked: however, measurement at only one dose rate is required for each detector at each energy.

The above test will be sufficient for the majority of instruments, except where they are specifically used to monitor very low energy photons (i.e. 30 keV or less). Testing of these instruments may require a specialist laboratory. Such tests may also be required for pulse-counting scintillation detectors because they have a low energy threshold which is determined in the set-up of the instrument's electronic system. These instruments are normally used to detect shielding leakage rather than to measure dose rate but, if they are used to monitor or identify potential supervised or controlled areas, the instrument response should be determined at an energy at or below the minimum likely in the workplace.

For the Periodic Test only, this test can be omitted if the QP is confident that there is no mechanism by which the low energy response could be altered that would not be identified at a higher energy. The test report should make this omission clear, referring to a document which gives justification.

4.4 Directional dependence of dose rate meters

The directional dependence test is required in the TBFU of photon and neutron dose rate meters: it is not necessary in subsequent Periodic Tests. It may be necessary to repeat the directional dependence test after any repairs that may affect the response of the instrument: this should be decided by the QP.

The majority of instruments are intended to respond isotropically to radiation incident over a wide range of angles, i.e. they are expected to have little directional dependence. This characteristic is normally investigated during Type Testing. However during instrument manufacture, it is possible to produce gross defects in directional dependence by, for example, omitting components in the energy compensation filter of a Geiger-Müller detector or in the internal, energy-correction, components of an ionisation chamber. These errors may not be detected in the energy dependence test.

The type test information should be inspected to identify the plane where the instrument response changes most with change of angle of irradiation; this is the most appropriate plane in which to perform the directional dependence test (frequently the horizontal plane). A test may also be required in the other plane. The instrument should be rotated in the selected plane about its reference point and its response at -90°, 0° and +90° compared. For photon dose rate meters, the radiation quality used should be that used in the low energy component of the energy dependence test; normally ^{241}Am γ radiation. A relatively low energy is preferable to ^{137}Cs or ^{60}Co γ radiation because the test is much more sensitive at the lower energy. Some instruments have a very low response at 90°, these should be tested at 60° instead and a note made on the calibration report. For neutron dose rate meters, ^{241}Am-Be, ^{252}Cf or accelerator produced neutrons of an appropriate energy should be used. The results obtained should normally agree with those in the type test data to within ± 30 %. If the instrument has more than one detector, it is essential that all are tested.

4.5 Background indication

The background indication of all detectors in an instrument should be checked. The result of this test should be recorded on the certificate or test report and compared with that suggested by the manufacturer and previous test results where available.

The background indication of dose rate meters should be checked in an area known to have a low, stable, background dose rate.

The background count rate of surface contamination monitors should be checked in a low background area. Typical background values for hand-held α contamination monitors, which are β and γ rejecting, should be less than 0.2 s^{-1}. If the background count rate is elevated, it could be due to contamination of the detector. In this case, the background should be reassessed after cleaning the detector and the result checked to ensure that it does not prejudice the detection of contamination at the maximum acceptable levels (as determined by the RPA) for the area of use. An elevated background may be acceptable in some areas if it is agreed with the RPA.

4.6 Confirmation of β response for β dose rate meters

This test is required for all β dose rate meters to identify instruments where, for example, the window thickness is different to that of the type test instrument or where the electronic threshold has been incorrectly set. Since β radiation is more strongly attenuated by detector windows than all but the lowest energy photon radiations, it is not possible to confirm the β response using photon radiation.

For β dose rate meters that are also used for photon dose rate monitoring, the β response should be confirmed after the photon dose rate tests have been completed. For instruments used purely for β monitoring, the response at high dose rates and instrument linearity should be investigated before confirming the β dose rate response.

The β dose rate test is best performed using a set of secondary standard β dose rate sources, so that a direct measurement of response can be made. Sources of, and associated filters for, ^{147}Pm, ^{204}Tl (or ^{85}Kr), and ^{90}Sr + ^{90}Y that conform to ISO 6980[17] can be used and are available commercially. Since it may not be possible to identify the minimum energy that could be encountered in the workplace, the test should be performed with three of the radionuclides listed above. The measured responses should agree with the type test data, as appropriate, to within ± 30 %.

However, since such source sets are only available at specialist calibration laboratories, an alternative method can be employed provided such a measurement formed part of the TBFU or the Type Test and the data are available for comparison or that a suitable traceable route exists for the cross calibration of such sources. The β response can be confirmed using a large area β contamination plaque of an energy at or below that of the minimum energy of use; the most appropriate radionuclide is usually ^{14}C. The result from the measurement (typically expressed as the indicated dose rate per Bq cm^{-2}) should be compared to the results from the type test data or TBFU.

4.7 Rejection characteristics

The β rejection characteristics of instruments designed explicitly for α monitoring should be checked by placing the detector 3 mm from the surface of a ^{90}Sr + ^{90}Y source. The instrument response, in terms of counts per second observed, should normally be less than 1 % of the response obtained for an α source of a similar emission rate.

The γ rejection characteristics of α contamination monitors used in areas of significant background photon dose rate should be checked by exposing the detector to the maximum dose rate likely to be encountered and checking that the background is not elevated beyond a tolerable level and that the net response to an alpha source is not reduced significantly. The gamma energy should be selected to correspond as closely as practicable to the energy anticipated. In many cases, the 60 keV gamma radiation from ^{241}Am will be appropriate.

The criterion above for the β rejection of α monitors also applies to the alpha channel of dual alpha and beta monitors. However, alpha activity will normally contribute

significantly to the beta channel count rate of dual probes, typically with an alpha to beta channel count rate ratio of 3 to 4 for ^{241}Am or ^{238}Pu. It is impossible to define a pass/fail criterion for the level of alpha counts in the beta channel; however the QP should use their knowledge and experience to judge if the measured values agree with expectations.

This test may not be necessary for instruments used to monitor areas of relatively high α contamination, where it is known that no significant β contamination is present, and which use detectors that are sensitive to both β and α activity, such as thin end-window Geiger-Müller detectors. In these situations, it is the responsibility of the RPA to advise as to the most appropriate action. If the rejection characteristics are not tested, this should be stated on the certificate or test report.

The γ rejection characteristics of neutron instruments should be tested using a ^{137}Cs or ^{60}Co source to ensure the response is not greater than 1.5 times that detailed in the type test data.

4.8 Light leakage

Scintillation and solid state detectors are susceptible to light leakage problems if the detector window is damaged. Light leakage tests are especially important in sodium iodide based detectors where damage to the window will lead to a progressive deterioration of performance because of the hygroscopic nature of the scintillator. On rare occasions, light sensitivity may also be observed with thin-windowed and glass-walled Geiger-Müller detectors.

Leakage from the window can be identified by exposing the instrument or probe to a bright light and checking that the background indication does not change significantly. In general, the source should be chosen to simulate the lighting conditions in which the instrument is likely to be used. For normal use, holding the detector either within 2 cm of a 200 W security light or within 12 cm of a 500 W security light should provide a satisfactory test. Note that the test should be performed quickly to avoid heat damage.

For α contamination monitors a further test should be performed by exposing the detector to a small α source. The instrument's response to the source should not change when a bright light is shone onto it. This test is important for α contamination monitors because it can identify the potentially dangerous condition when there is a loss of function in the scintillator without a corresponding increase in background count rate.

4.9 Response to contamination

Each type of contamination monitor should be checked to ensure its response is satisfactory to the particular type(s) of radiation with which it is intended to be used. If a substantial number of monitors is calibrated, it may be convenient to manufacture jigs to ensure that the detector is held reproducibly at the correct distance from the source.

For α and low energy β sources that are used to calibrate monitors with detector areas smaller than those of the source, a single measurement position is sufficient. The instrument reading should be determined with the detector positioned centrally above a calibration source of known emission rate, at a source - detector separation of 3 mm (see Section 4.9.1) and the instrument response should be calculated.

$$\text{Instrument response (emissions)} = \frac{R - B}{SER}$$

where R is the observed reading (s^{-1})
B is the background count rate (s^{-1})
SER is the surface emission rate per unit area of the source (s^{-1} cm^{-2})

To convert the instrument response to counts per second per Becquerel per unit area, a P-factor must be applied (see Section 4.9.4),

$$\text{Instrument response (activity)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER.P}$$

where P is the appropriate P-factor.

Another quantity of interest is the 2π efficiency:

$$2\pi \text{ efficiency} = \frac{R - B}{SER.A_p}$$

where A_p is the nominal probe area

For larger area alpha and beta monitoring instruments, it may be necessary to use the contiguous portions technique to simulate a source which has dimensions larger than the detector (see Section 4.9.2). In theory, more distant activity will also be detected to

a degree but, for most instrument types at a 3 mm source to detector separation, the response is dominated by the activity immediately below the detector window.

A problem occurs with very small probes, where the contribution from activity beyond the edge of the window will produce a significant increase in count rate compared to a source of the same dimensions as the probe. This effect increases as the window to source distance increases. This is a limitation in the concept of 2π efficiency.

Some beta detectors have an ill-defined averaging area. These are cylindrical and are normally held in a tubular housing with a shield that can be rotated to expose the detector. The best calibration approach for these instruments is to reproduce the geometry employed in the Type Test. If this geometry is inconvenient for routine calibrations, then a detector which conforms to type can be used as a transfer instrument to determine the correct count rate from a source in a more convenient geometry. This new geometry can then be used for future testing of instruments of the same type against the transfer instrument.

For low energy photon monitors a similar approach to that for beta monitors can be used but it should be noted that these are more susceptible to the effects of activity located beyond the probe window.

The situation for instruments used to monitor high energy photon contamination is more complicated; these range from simple ratemeters with an energy threshold to isotope identifiers with full spectrometric capability. Such instruments often use large scintillation detectors which are sensitive both on the end and the side of the crystal. Type test data may be available in several forms:

a) Detection efficiency for defined radionuclides at defined distances;
b) Instrument response (activity) at a defined distance to a large area source[11];
c) Detection efficiency for defined radionuclides at defined distances and a specified energy resolution, often for ^{137}Cs gamma radiation;
d) Gamma dose rate response, in terms of counts s^{-1} μGy^{-1} h, generally for ^{137}Cs gamma radiation.

In addition, for many crystal materials and sizes, generic detection efficiency and photofraction data can be used[23]. These data will be particularly useful when assembling a ratemeter/detector combination produced by different manufacturers.

Where it is impractical or inconvenient to reproduce the type test geometry regularly, the best approach is to use a transfer instrument (as described above for beta contamination monitors) to determine the expected response for a new geometry. For example, the detection efficiency of a large crystal can be confirmed using a ^{137}Cs point source under good geometry, i.e. in low scatter conditions with the source at several detector dimensions from the detector surface. The results should be expressed in terms of counts s^{-1} Bq^{-1} cm^2. A less active source can then be positioned at a much shorter distance to give the same net count rate. The less active source and reduced distance can then be used as a geometry for future testing of other instruments of the same type.

The pass/fail requirement for surface contamination monitors is that the response to contamination agrees within ± 30 % of that specified by the manufacturer.

Contamination instruments scaled in dosimetric units can be tested using a conventional dose rate calibration facility, provided the available dose rates are low enough and stated in terms of dose rate above background (correcting for background could be difficult since the background response of the instrument under test could be very different from that to the same air kerma rate from the calibration radionuclide).

4.9.1 Source to detector separation

For the purpose of this document, the source plane is regarded as the active surface of the source, i.e. beneath any filter permanently fitted. If a detector is placed and allowed to stand freely on a flat surface, the plane of the detector in contact with the surface defines the detector plane. Source to detector separation is then defined as the distance between the source plane and the detector plane. Figure 1 illustrates the source plane, detector plane and the source - detector separation.

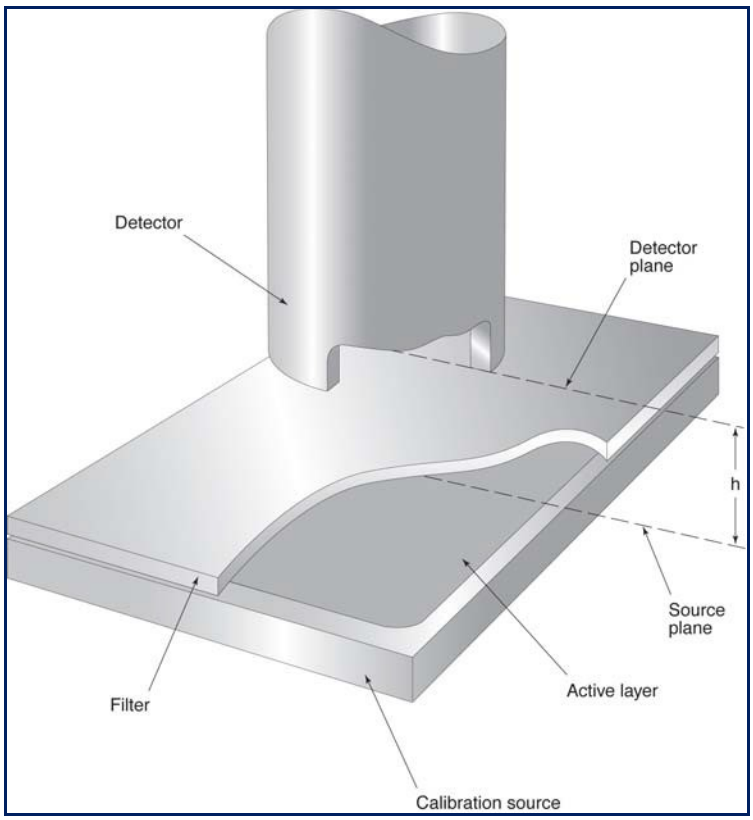

Figure 1: Definition of source-detector positioning

4.9.2 Contiguous portions calibrations

A large area calibration source of standard dimensions (100 cm^2 or 150 cm^2) can be used repeatedly to simulate a larger source. By placing the calibration source in successive positions, a source of the desired dimensions can be simulated. The net instrument readings observed in those positions can then be combined to obtain the total indication of the detector that would have been observed if a sufficiently large source had been available.

A grid should be drawn up to outline the adjacent, but not overlapping, source positions in which measurements are to be made: note the grid should accommodate

only the active area of the source, not the rim. The number of source positions used in the grid should be sufficient to cover the whole area of the detector or desired area. Use of a grid, as illustrated in Figure 2, serves to minimise errors in positioning the source and hence reduces any additional contribution to the overall uncertainty in the calibration.

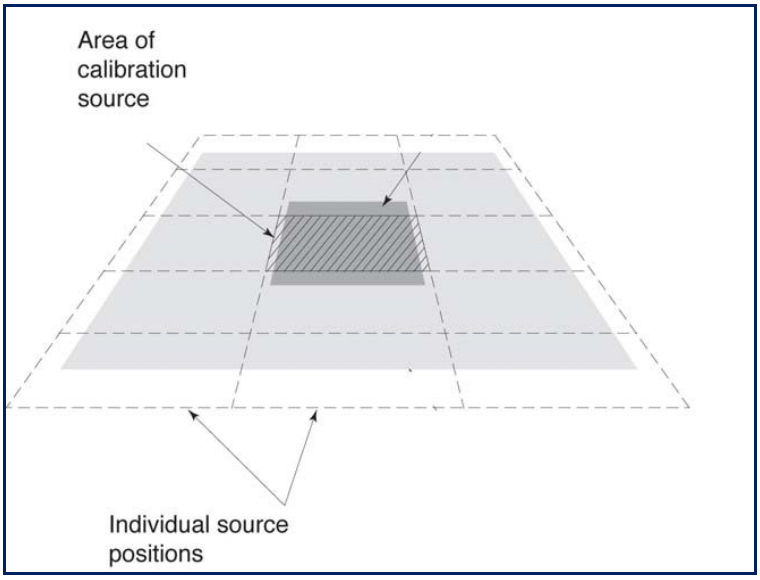

Figure 2: A measurement grid

With the detector fixed 3 mm above the central position, the source should be placed in each of the grid positions in turn and the observed instrument readings recorded. The observed readings (R_i), should then be background corrected (R_i - B), and summed to obtain the corrected total detector indication ($\sum(R_i - B)$). Division of the corrected total detector indication by the surface emission rate per unit area of the source (SER), allows the instrument response in terms of counts per second per emission per unit area to be calculated.

$$\text{Instrument response (emissions)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER}$$

where R_i is the observed reading at source position i (s^{-1})
B is the background count rate (s^{-1})
SER is the surface emission rate per unit area of the source (s^{-1} cm^{-2})
n is the number of source positions.

To convert the instrument response to counts per second per Becquerel per unit area, a P-factor must be applied (see Section 4.9.4),

$$\text{Instrument response (activity)} = \frac{\sum_{i=1}^{n}(R_i - B)}{SER.P}$$

where P is the appropriate P-factor.

The main problem with high energy photon contamination monitoring is that most instruments have both end and side sensitivity. As a consequence of this, the detector responds to activity which is a long way away. In effect, the response to unit activity per unit area is proportional to 1/h rather than $1/h^2$, where h is the distance from the source as defined in Section 4.9.1. This is because the response to a point source falls according to $1/h^2$ but the corresponding area at that distance rises with respect to h. Hence, for instrument testing, it is essential to have a defined area specified which can be reproduced at each test. It may be convenient for that defined area to be the averaging area used in practical monitoring.

In many circumstances, the contiguous portions process can be simplified to two measurements, one with the source below the detector and one with the source at a specified radial displacement. These can be compared with the results from the corresponding positions from the full contiguous portions test. If good agreement is observed, then the instrument response can be assumed to be unchanged. If calibrations are performed using the contiguous portions technique, the test laboratory should state the dimensions of the effective source used on the certificate, so that results of previous and future calibrations may be compared.

4.9.3 Standard calibration sources

The large area sources used to calibrate contamination monitors should conform to the specifications detailed in BS ISO 8769[18]. While it is not necessary to use Class 1 reference sources (the most precisely characterised sources calibrated at a national standards laboratory), the sources used must have been calibrated in terms of surface emission rate with known traceability to national standards.

The radionuclides selected as sources for the calibration of contamination monitors should reflect the range of types and energies of radiation to be monitored in the workplace; suitable radionuclides are listed in BS ISO 8769[18]. For α contamination monitors, suitable radionuclides for calibration sources are ^{241}Am and ^{238}Pu, and, where a low energy standard is appropriate in the workplace, ^{230}Th or ^{234}U. For β contamination monitors and photon contamination monitors, one of the radionuclides selected for the test should have an energy equal to or less than that of the minimum

energy to be monitored in the workplace: ^{14}C is recommended for all wide energy range beta detectors.

For photon monitoring instruments, problems with source selection can arise because it is often difficult to determine the particular energy component which generates the signal in the detector. For example, ^{99m}Tc generates a photon of approximately 140 keV at 89 % abundance and 18 keV photons at 6.4 % abundance[24]. For some detectors the detection efficiency for the 18 keV photon may be thirty times greater than that for the 140 keV photon and hence the bulk of the signal is generated by the 18 keV photon. When testing such an instrument for use with ^{99m}Tc it is therefore essential to check its response at or below 18 keV; a suitable calibration source would be ^{55}Fe. For instruments only used above 30 keV, ^{129}I would be suitable, as described in BS ISO 8769[18].

4.9.3.1 Source uniformity

Sources of poor uniformity, i.e. those that have areas which deviate significantly from the mean emission rate of the whole source, can have a detrimental effect on instrument calibrations if the non-uniformities are not accounted for. If the emission rate distribution and uniformity of a source are known, it may be possible to identify a source orientation which ensures that no highly deviant areas are used repeatedly.

The requirement for the uniformity, or homogeneity, of Class 1 reference sources provided in the second edition ISO 8769[18], is that the relative experimental standard deviation derived from the emission rates from each individual portion of the whole source shall be no greater than 5 %; the corresponding requirement for Class 2 sources is 10 %. The source portions shall be, of equal area, 5 cm^2 or less. It is the view of the authors and the IRMF that Class 2 reference sources are sufficient in order to achieve the precision required in the calibration of portable surface contamination monitors for most routine applications. It is the recommendation of this guidance that laboratories using reference sources manufactured in accordance with the first edition of BS ISO 8769:1988, continue to do so until they would otherwise have replaced them. It is advised that the uniformity of such sources is redetermined using the techniques described in the second edition of the standard (using 5 cm^2 portions rather than 10 cm^2). It should be noted that ISO8769 is under review at the time of publication of this guide.

Appendix 5 contains detailed information about the selection of a detector for use in the determination of the uniformity of reference sources. Techniques to estimate an effective source emission rate that can be used for instrument calibrations, as an alternative to the methods described in this Section, are also provided; these may be

useful if reference sources are highly non-uniform or if a greater level of precision is required in the instrument calibration.

To determine the uniformity of a source, it should be divided into equal portions of area not greater than 5 cm^2. A mask, of sufficient density and thickness to attenuate all of the particulate emissions from the source, can be used to cover all but one portion of the source (see Figure 3). This allows the instrument reading generated by exposure to each portion of the source to be determined in turn. It is important to keep the detector fixed in position relative to the mask while making the measurements so that the effect of variations in detector efficiency across the detector face are minimised. The uniformity of the source is given by the relative experimental standard deviation of the net (background corrected) instrument readings.

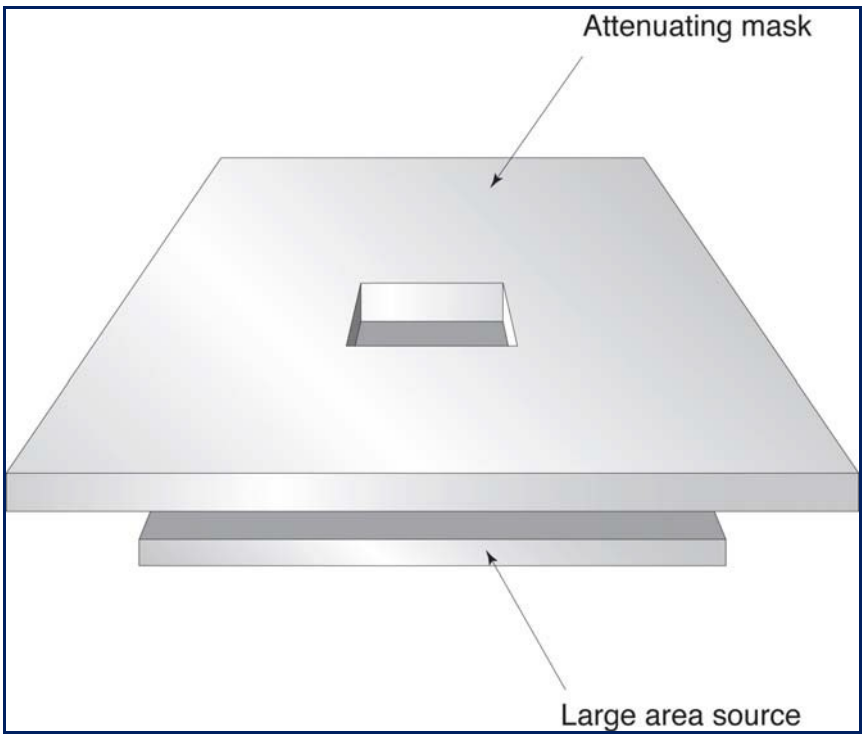

Figure 3: The use of a mask to simulate a small area source

For low photon energy sources, such as ^{55}Fe, a mask can be used as mask penetration will be low. For the 60 keV component from ^{241}Am, the same approach can be used with a lead mask 2 mm thick but for higher energies, such as ^{57}Co, even lead will be penetrated to some extent making any correction for non-uniformity difficult.

4.9.4 P-Factors

For radiation protection purposes, it is necessary to determine contamination levels in terms of Becquerels per square centimetre (Bq cm^{-2}). However, it is not generally possible to calibrate directly in terms of Bq cm^{-2} because the activity of the calibration source is not known: only its surface emission rate can be determined accurately and is traceable to national standards. The measurement processes described above give results in terms of instrument response or detection efficiency but these are not useful quantities for the end user in most circumstances.

For reference sources of single energy α or β emissions used for the purposes of calibration, a P-factor is the ratio between the activity per unit area of a source and its surface emission rate per unit area; note this is a working simplification for use only in a calibration environment. P-factors are dependent upon both radiological and physical characteristics of the source, most notably, the decay scheme of the radionuclide, the thickness of the layer in which the activity is deposited and the degree of backscattering taking place inside the source or from the surface on which it is resting.

For an ideal source in which the activity is deposited in a thin layer on the surface of a thin substrate, where little self-absorption and backscattering is occurring, a P-factor of two is appropriate for most α and β radiations: hence one particle emitted per second is equivalent to 2 Bq for a 100 % decay**.** It is recommended that for the purpose of calibration, test sources are assumed to be perfect and a P-factor of 2 is employed for a 100 % emission. This is a working simplification which will allow the use of sources of different construction. In a realistic monitoring environment where the radionuclides present and their distribution are significantly more complicated, the definition given above is oversimplified. It is therefore the responsibility of the instrument user's RPA to advise on the appropriate P-factor for use during practical monitoring. This advice should take into account the complexity of the radionuclide mix, surface form and any surface coating, such as paint or grease. Further guidance on P-factors is available in GPG30[3].

Where the calibration source is a parent-daughter combination, for example $^{90}Sr + {}^{90}Y$ in equilibrium, where both are detectable by practical instruments, it should be made clear that the activity quoted on the certificate refers to the total activity and therefore the combined emissions.

The test house may convert the metrologically robust measurement of the instruments response in emissions into the operationally convenient value, count rate per Bq per cm^2. The laboratory should state any P-factor applied on the calibration certificate, thus allowing the user to apply a different value if more appropriate.

4.10 Linearity of response of contamination monitors

The following test is suitable for α and β surface contamination monitors, including dual probes. Some β surface contamination monitors can also be tested using photons: tests for these and for X and γ surface contamination monitors are outlined at the end of this Section.

The linearity of α and β contamination monitors is checked using a set of sources of known emission rate of α and β particles respectively. Suitable radionuclides are ^{241}Am for α monitors and $^{90}Sr + ^{90}Y$ or ^{36}Cl for β monitors. A satisfactory test for the simplest class of instrument can usually be accomplished using three point sources, of identical construction, with emission rates spanning the range of count rates that the instrument may reasonably encounter in the workplace. Each source should be placed, in turn, in a fixed and reproducible geometry with respect to the detector: suitably manufactured jigs could be used to ensure reproducibility of the detector and source positions. The instrument response should be determined for each source and the mean of the responses should be calculated. Each of the individual responses established should then agree with the mean response to within ± 30 %.

X and γ surface contamination monitors can also be tested in a similar way. Instruments intended for use at low photon energies will often respond effectively to $^{90}Sr + ^{90}Y$ beta radiation. Other instruments may respond to the 60 keV gamma radiation from ^{241}Am. This may mean that no specific sources need to be purchased for the calibration of these monitors.

For β contamination monitors which respond to photons, and for X and γ surface contamination monitors, the procedures described for testing the linearity of dose rate monitors can be followed: however, the minimum dose rate selected will depend on the particular instrument sensitivity (see Section 4.2). For most instruments, the lowest dose rate used should correspond to a total count rate of approximately three times the background count rate, or a minimum of 5 counts per second, whichever is greater. The response of the instrument should be linear to within ± 30 % of the mean of the measured responses at normal operational levels.

For digital instruments with stored dead time correction factors, it may be sufficient to make measurements at high and low count rate points for each detector. It is important

that the instrument design is checked to ensure that this is a valid method and that there are no mechanisms, such as any automatic electro-mechanical switching, for the instrument to deviate significantly from specification without it being obvious at either or both points. At minimum, a written statement from the manufacturer is required which confirms the validity of this method.

4.11 Uniformity of response of contamination monitors

Instruments with a detector area in excess of 40 cm^2 should be checked to ensure that their response to appropriate radiations is reasonably uniform over the whole area of the detector. This test is designed to identify areas of the detector which have inadequate detection efficiency: it is particularly important for α and β scintillation detectors where the scintillator can become detached from its support plate or light guide. Note that for some detector types, particularly large area scintillation detectors, variations of a factor of 2 between the most and least sensitive areas can be observed.

The test should be performed using a small diameter source (10 - 25 mm) of known particle or photon emission rate as described for the linearity testing (Section 4.10); only one source need be employed. The energies of β and γ radiations used for this test should be equal to, or below, the minimum energy to be monitored in the workplace. If a small area source is not available, a suitable alternative for relatively non-penetrating radiations is to mask a large area source down to a small area (see Figure 3). It should be noted that, for photon emitters, there may be some contribution to the response which arises from collimator scattering and/or transmission through the mask; this effectively blurs the area of the detector which is being examined.

For dual α and β probes, the uniformity of the α and β responses should be tested separately.

To determine the uniformity of a detector, the instrument reading should be noted as each 10 cm^2 of the detector window area is exposed to the source in turn. The mean indication over the whole detector area should then be calculated. The criterion for the test is that no more than 30 % of the total probe area should have an instrument response which is less than 30 % of the mean.

4.12 Testing for use in unusual circumstances

By its nature, the testing of instruments for use in unusual circumstances is difficult to define. The RPA, advised by the QP, should identify situations where an instrument is to be used in an unusual manner, i.e. those situations which the manufacturer could not reasonably have anticipated during the design of the instrument or those which are outside the instrument's specification but where successful performance would lead to

an operational advantage. Such circumstances could include, for example, using an instrument with a conventional meter upside down where any meter imbalance will result in a different indication or, at a temperature higher than the maximum specified. It is important that the manufacturer is consulted before embarking on testing for such purposes. While manufacturers may be reluctant to state that an instrument is likely to work in situations beyond its specification, they will often confirm when it definitely will not function correctly. The National Physical Laboratory may also be contacted to obtain suggestions or information about suitable testing from the radiation metrology community.

The QP and RPA should design tests which will identify whether the performance is adequate for the use intended. The necessity of some tests may be obvious, such as performing function checks and a linearity test on an instrument with a moving needle while it is being held upside down. Defining specific tests for instrument use at higher temperatures is more difficult. The instrument must satisfy two requirements: firstly that it operates correctly at the high temperature and, secondly, that its operation at high temperatures has no long-term implications for its performance in routine conditions (such as insulator deterioration within the instrument, the detector and in any probe to ratemeter cable).

The nature, scope and rationale of any tests performed should be clearly documented along with the results.

5 Facilities

The TBFU and the Periodic Tests should be performed in appropriate radiation facilities. The facilities should be able to provide the range of radiation fields required for testing. The recommendations of the International Organisation for Standardisation, the United Kingdom Accreditation Service[25], and the International Atomic Energy Agency[26] may be helpful but compliance with them is not mandatory for the tests required by the regulations. Very elaborate facilities such as those which may be found in large organisations, nuclear installations, UKAS accredited and other laboratories of comparable standing may not necessarily be required. The basic requirements for most tests are a selection of suitable sources and a calibration track or other device capable of providing a range of dose rates. The conventional true value of the dose rate at the point of test should be known to within 10 %. A detailed knowledge of the scattering characteristics of the facility is necessary for the calibration of neutron meters.

Test rigs should be available so that overall uncertainties due to the positioning of the reference point of the instrument at the point of test, or positioning of the source, are less than ± 5 % at dose rates within the normal range of use.

Where reasonably practicable, remote handling of radiation sources should be used to minimise personnel exposure, and remote reading of instrument displays is recommended. The test facilities for dose rate meters will usually be controlled areas and the necessary radiation protection measures must be taken.

All tests should be performed under suitable conditions of temperature and humidity. Some instruments require correction for temperature and pressure if the values vary significantly from standard conditions (20°C and 0.1 MPa), or from the conditions under which the instrument was type tested.

6 Traceability

Measurements used to demonstrate compliance with the regulations should be traceable to national standards of measurement. It is necessary to establish the route of traceability to national standards and to estimate the uncertainties in measurements[27,28]. As a general rule, publications from BSI, IEC, ISO and UKAS should be consulted; accreditation to ISO 17025[29] is not obligatory to comply with the regulations, but is best practice.

The testing of an instrument calibration should be performed using sources or equipment that ensure known accuracy, via the traceable quantity, in relation to national standards. Traceability to primary national standards can be achieved by testing instruments against an appropriate secondary standard device at a laboratory employing a formal scheme of quality assurance. In the UK, traceable calibrations are provided through laboratories accredited by UKAS and by other laboratories using secondary and tertiary standards.

Secondary standards include ionisation chambers for X and γ-ray fields, source and filter assemblies for β dose rate measurements and large and small area sources for α, β and photon surface contamination. These secondary standards should be calibrated by the primary or national laboratory at least every four years, with the best overall uncertainties usually of the order of ± 5 % at the 95 % confidence level, (these being the combined Type A and Type B uncertainties as defined by UKAS[27]).

Radionuclide sources of neutrons, with traceable output or activity, may also be used as secondary standards, provided they are mounted and used in a way that avoids significant errors from scattered radiation. The recommendation for these neutron sources is that, when new, they are recalibrated at least every five years or every half-life, whichever is shorter; this is necessary to check that the levels and effects of any impurities present are clear. Once sufficient data have been accumulated to provide confidence in the output of a source, the frequency of calibration may be reduced. Since there are significant uncertainties associated with the conversion coefficients for fluence to ambient dose equivalent for neutrons, uncertainties in the calibration of secondary standard sources are usually of the order of ± 10 % at the 95 % confidence level. For photon sources that may contain impurities, the same approach is recommended.

Tertiary standards include similar devices and sources, which have been compared, not with the primary standard, but with an appropriate secondary standard. Tertiary

standards should be calibrated against a secondary standard at least every four years and be the subject of a comparison check every two years. As tertiary standards are generally more frequently used at a working level, they are more vulnerable to loss of calibration and therefore require more regular calibration against the secondary standard.

7 Certification of tests

IN THIS CHAPTER

- Test Certificate
- Test Label

The results of tests performed under the current regulations[1] should be documented and communicated to the employer in a formal manner. If an instrument fails to meet the pass/fail criteria of any component of a test, the calibration or test laboratory should prominently label the instrument as failed and make some indication of the nature of the failure on the test report or certificate.

7.1 Test certificate

The precise format of a test document is not specified in the regulations, but the test house should provide the following basic information:

a) the name and address of the customer or user;

b) a description of the instrument (including type, serial number and unique identifier);

c) the intended use of the instrument. Where it is not possible to determine this then the range over which it has been tested should be specified. For example, for a beta contamination monitor, a suitable phrase for many instruments is "Monitoring of beta surface contamination for radionuclides with a maximum energy in excess of 150 keV";

d) the type of test, i.e. TBFU, Periodic Test or Retest After Repair;

e) any limitations of the tests performed including identification of the output modes or ranges not tested;

f) the value of the dose rate used for the high dose rate test;

g) a basic description of the test, any specific instrument settings used which may be readily modified by the user, any significant deviations from the manufacturers recommended settings and any adjustments or repairs performed;

h) the results of the tests including instrument response or the calibration factor for specific radiations and a statement of the uncertainty with the confidence level at which the uncertainty is quoted;

i) a record of the background dose rate or count rate and any relevant environmental conditions during the tests;

j) the value of any conversion coefficient or P-factor applied to the results;

k) a statement that the test was carried out for the purpose of the regulations and the test criteria were met;

l) where appropriate, the indication produced by any check source supplied with the instrument or from a generic check source if a similar source is available to the end user;

m) the name and signature of the QP supervising the test;

n) the name, address and contact details of the laboratory at which the test was performed;

o) the date of the test;

p) the certificate reference number.

If contiguous portions measurements were performed for a surface contamination monitor, details should also be provided about the dimensions of the effective source used and the orientation of the wide area reference source(s) with respect to the monitor.

If the test was unsuccessful i.e. the instrument failed, this should be formally communicated, in writing, to the customer. This should be unambiguous and there should be no possibility of confusion with a successful test document.

7.2 Test label

As test documents are usually filed away for Quality Assurance purposes and tend not to accompany instruments in the workplace, it is recommended that instruments which are satisfactory are labelled with the following information after testing:

a) unique identifier(s) of the instrument;

b) the date of calibration or test;

c) the certificate reference number.

Where an instrument consists of a ratemeter and one or more probes, both the ratemeter and the probes should be labelled with the unique identifiers of each component of the instrument. Any instrument which has failed should be prominently labelled accordingly.

8 Quantities and units

Throughout this document the term ‘dose’ has been used as a general term for various dose equivalent quantities. A brief description of these is given here.

In The Ionising Radiations Regulations, 1999[1], the dose limits for whole body external irradiation are expressed in terms of the protection quantity, *effective dose, E*. This quantity is a weighted average of dose equivalents in various organs of the human body and is considered to be immeasurable.

In ICRU Reports 39[12] and 43[13], the operational quantities *ambient dose equivalent H*(10)* and *directional dose equivalent H'(0.07)* were proposed and expanded upon; these can be measured and provide an adequate approximation for *effective dose* so current practice is to calibrate portable radiation protection instruments in terms of the operational quantities. The current conversion coefficients for the operational quantities are contained in ICRU Report 57[30] and ICRP Publication 74[31].

Primary standards for photons and electrons are realised in terms of the quantities air kerma and absorbed dose respectively: for neutrons, the corresponding primary quantity is neutron fluence. Certificates issued by national standards laboratories when calibrating secondary standard instruments usually quote these quantities: note that for electrons, certificates will normally be in terms of absorbed dose in tissue.

Published conversion coefficients can be used to convert the quantities above to the required operational dose equivalent values: BS ISO 4037-3[16] gives values for all the gamma and X ray qualities currently employed in testing while BS ISO 8529 Part 3[21] provides coefficients for neutrons.

For contamination monitors, the traceable quantity is the surface emission rate of the reference source. Instrument calibration certificates sometimes quote the instrument response (emissions) in terms of the number of source emissions but may also quote the response in terms of the contamination activity. To convert the instrument response from emissions (cps per emission per cm^2) to activity (cps per Bq per cm^2), a P-factor must be applied (see Section 4.9.4).

The Units of Measurement Regulations, 1986[32] (as amended) implementing an EC Directive[33], stipulate the use of SI units in any measurement required for economic public health, public safety or administrative purposes: the results of the TBFU and the Periodic Tests should therefore be given in SI units, whether or not the instrument is scaled in them. Users of instruments scaled in non-SI units are encouraged to rescale

them or purchase new instruments. An instrument scaled in the old units may, however, be used in compliance with the Ionising Radiations Regulations[1], provided the appropriate response or calibration factor is used to convert to SI units when compiling the records: any response or calibration factors given in test certificates should therefore relate to SI units.

Appendix 1: Function checking

Function checking is an important part of maintaining confidence that an instrument is performing correctly. It is a limited test but it can usually be done with an easily accessible and transportable source.

A1.1 Audio output

Many instruments have an audio output facility; this should be checked to ensure it is operating according to the instrument type.

A1.2 Function check sources

Historically, aluminium cylinders containing a thin, 25 mm disc of Uranium were often used as function check sources. The cylinder cap was unscrewed and the instrument presented to the exposed source. Uranium has the advantage that it emits alpha, beta and photon radiation and, hence, most contamination monitors would display a reasonable count rate when exposed to it. However, such sources have become increasingly unacceptable in the workplace.

Simulant Uranium discs containing small quantities of ^{241}Am, ^{90}Sr and ^{137}Cs are available and make a reasonable replacement for the Uranium disc. Alternative function check sources are generally small area sources of: ^{241}Am for alpha detectors; ^{14}C, ^{36}Cl or ^{90}Sr + ^{90}Y for beta detectors; and, ^{241}Am or ^{90}Sr + ^{90}Y for X ray detectors*; and, ^{137}Cs for high energy photon detectors. Function checking of neutron detectors is more difficult as most users do not have access to a suitable source, for example, ^{241}Am-Be. However, high activity (GBq) ^{241}Am gamma dose rate sources frequently emit sufficient neutrons to be used for this purpose.

There is a significant problem with test sources for some high dose rate meters, particularly those which autorange between high sensitivity (i.e. low dose rate range) detectors and low sensitivity (high dose rate range) detectors. The dose rate required may be so high that the function check source itself becomes a major hazard. In this situation, alternatives include:

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* These two radionuclides were selected for checking X ray detectors because ^{241}Am generates a 60 keV γ for 36 % of decays and a similar fraction of 11 to 20 keV L X rays, both of which are generally detected by low energy X ray monitors. ^{90}Sr + ^{90}Y is also sufficiently energetic to penetrate the relatively thick beryllium or aluminium windows that these detectors often use.

a) for thin windowed ionisation chamber instruments, MBq activity $^{90}Sr + ^{90}Y$ will produce indicated mSv h^{-1} dose rates and are relatively easy to shield;

b) for telescopic Geiger-Müller based instruments it is sometimes possible to gain access to stable high dose rates via a penetration into a cell;

c) using industrial radiography exposure units (generally employed for testing installed instruments) where available and where it is possible to put sufficient local shielding in place.

A suitable check source is one which:

a) has a sufficiently high activity to allow a fast, but reasonably accurate, estimate of the instrument reading to be made;

b) results in an instrument reading that is reasonably sensitive to energy threshold, i.e. a user will observe that the function check reading has changed before any practical monitoring is compromised. Generally this requires a significant fraction of the radiation to be at or below the effective instrument energy threshold;

c) requires minimal administrative burden as a result of owning it and making it easily available; and,

d) has a sufficiently long half-life to allow only an annual update of acceptable instrument count rate ranges.

The absolute emission rate from a function check source is not important. Traceability is best maintained by determining acceptable count rate ranges for specific instruments at occasional intervals, such as every 4 years.

In large establishments where many function check sources are used, it may be worth maintaining a dedicated transfer instrument (such as one of the probes which are routinely tested, connected to a digital integrating instrument) that can be used annually as a quality control to check for any possible damage to the sources, in terms of loss of activity or the build-up of grime on the surface of the source.

A1.3 Determining acceptable count rate ranges

The use of a function check source requires the provision of an acceptable count rate range for each instrument type with which it is anticipated the source will be used. These acceptable ranges can be determined by:

a) establishing a reproducible geometry, for example, by use of a jig;

b) selecting a number of instruments of each type that have a response range that has been shown to conform to type;

c) exposing each instrument to the function check source and recording the net instrument reading;

d) determining the maximum, minimum and mean instrument readings for each instrument type;

e) using these to determine the acceptable range which is then adopted for each instrument type and function check source combination (the acceptable range should be decided by the QP and the RPA but will usually be slightly wider than the observed count rate range);

f) establishing the acceptable background count rate range for the environment in which the instrument will be used.

Appendix 2: Repairs, replacement and retesting of instruments

Instruments suffer from damage and deterioration in service and, to a lesser degree, in storage. It is necessary for a QP to make a judgement regarding the extent of testing required after exchange of components or repair and to define the acceptable tolerances on that testing. This Appendix discusses the scope of testing required after examples of such repairs.

Personnel carrying out instrument repairs should be suitably trained to do so.

A2.1 Changing leads on scintillation detector based contamination monitors

Leads frequently become damaged. Where these are easily removable, i.e. are fitted with screw or bayonet connectors at each end, the complete lead can be freely replaced by one which is effectively identical, i.e. the cable is the same length and the same specification with connectors of the same type. The instrument can be returned to service if it passes an appropriate function check; no further retesting is necessary.

A2.2 Changing leads on Geiger-Müller Detector based contamination monitors

Easily replaceable leads can be replaced by leads which are effectively identical, i.e. the cable is the same length and the same specification with connectors of the same type. However, it is also necessary to confirm the continuity of the screen and core of the cable are identical as, unlike scintillation detector types, operation at low levels draws very little current and poor continuity will not be apparent. The instrument can be returned to service if it passes an appropriate function check; no further retesting is necessary.

A2.3 Changing probe windows on scintillation detector based contamination monitors

The thin aluminised melinex windows used on many contamination probes are very easily damaged. The windows can be replaced by others which are effectively identical without requiring adjustment or major retesting of the instrument. The most important radiological criterion is the mass per unit area of the window material: this can be checked using a source with an energy close to the minimum useful energy for the probe in question (for example, ^{14}C) and one of the following techniques. After a window repair has taken place the probe can be positioned over a source and the count rate recorded. Any significant deviation in count rate from a previously determined or expected value will indicate that the window mass per unit area differs from the expected value. A significant reduction in the count rate indicates a thicker window which may compromise practical monitoring. A higher result may mean that the new

window is thinner and more delicate. Alternatively, a source and a monitor can be set up and used to confirm that the observed count rate drops by the expected value when each new replacement foil is placed between the source and monitor; this should be done when a new batch of foils is accepted into the workshop. This approach can be applied with confidence if only one thickness of window is used in the workshop. It is important to ensure that the foil manufacturer is also careful with quality control of their products, and if any refoiling fails these tests then the whole batch of foils should be regarded as suspicious.

It is also necessary to ensure the probe is light tight after repair: this should be checked using the light leakage test described in Section 4.8.

The instrument should be subject to a function check before being released back into service.

A2.4 Mechanical repairs

Switches, sockets and handles frequently work loose; users are encouraged to arrange for repair of such items promptly before significant problems arise. External repairs will not normally require retesting. Repairs requiring access to the inside of the case can result in further accidental damage taking place during the repair or the identification of other damage in service that may have occurred but previously gone unnoticed. An instrument should therefore, generally, be subject to a Periodic Test after internal repairs.

The desiccant in ionisation chamber instruments needs to be dried regularly. In many instruments, access is easy and there is no risk of damage; only a function check after drying is required. In other, generally older, instruments where significant dismantling is needed to access the desiccant, a Periodic Test should be performed after drying.

Appendix 3: Photon dose rate tests

This Appendix provides additional details and describes some specialist facilities that may be required to perform the tests on photon dose rate meters effectively.

A3.1 Instrument positioning

Sophisticated equipment is not necessarily required for positioning the instrument; it can be a simple stand with two reference lines marked on it so that the detector reference point can be positioned in the right place: a stand with optical alignment and variable height would be appropriate. Whatever form is chosen, the support should be light to minimise scatter but also rigid to ensure repeatability of positioning.

The method of observing the instrument reading should be chosen to avoid significant operator doses: a closed circuit TV camera mounted on a flexible arm would be suitable. For digital instruments, positioning of the camera is not critical. For instruments with conventional meters, the axis of the camera lens should be normal to the meter and in line with the meter pivot to avoid parallax issues.

A3.2 Calibration of photon dose rates

Photon dose rates used for testing purposes are normally measured using a high quality ionisation chamber with an associated electrometer. The ionisation chamber should have a secondary or tertiary standard calibration and the electrometer should also be appropriately calibrated. Any other ancillary equipment, such as thermometers and barometers that are used to make corrections for air density during the calibration, should also have a traceable calibration with an appropriate degree of accuracy.

Alternatively, especially for low dose rate facilities, an energy-compensated Geiger-Müller detector connected to a precision scaler may be used to provide an easy and reliable means of calibration. The detector(s) should be chosen so that the sensitivity is adequate at the lowest dose rates while the uncertainty generated by the dead time corrections at the highest dose rate should be less than 10 %. The combination of detectors should be calibrated as a tertiary standard by an appropriate laboratory.

For facilities testing only a limited range of instruments, the use of a transfer standard instrument is an alternative method and can offer advantages such as closer approach to a source without significant loss of accuracy. A transfer standard is an instrument, of the same type as the instrument to be tested, that has been calibrated by an appropriate laboratory as a tertiary standard. This instrument is then used to determine the value of dose rate or emission rate for an instrument of the same type and set up, at the same distance and using the same source: many instruments can be tested using this method. The tests can be carried out using quite compact jigs with low external

dose rates. However, the dose rate derived from an instrument of one type is not transferable to an instrument of another type, especially in the case of a compact jig as the influence of any scattered radiation is very dependent on instrument type.

A3.3 Variation of dose rates

The dose rate observed by an instrument may be varied by using a set of sources with different activities, changing the source to detector distance, changing the apparent source diameter, or by inserting absorbers into the beam.

If using a set of sources of various activities, the activities should be chosen so that the whole dose rate range required can be covered effectively. If a track is used to vary the source to detector distance, the source with least activity should generate a dose rate at the farthest position on the track that is low enough to establish the bottom point on the most sensitive instrument. Equipment with distributed sources of large dimensions and aperture plates is also available from manufacturers, which changes the output by varying the apparent source diameter.

The method of using absorbers to attenuate the primary beam is acceptable for instruments with little energy dependence when compared to the reference (secondary or tertiary) instrument: however, it can lead to problems when used for instruments which are highly energy dependent, mainly because of Compton scatter within the absorber generating low energy radiation (see Section A3.4).

A3.4 Photon beam collimation

Any photon source used to calibrate instruments should have a properly designed collimator that restricts the beam size to the minimum required. This serves to limit scatter, reduce operator doses for hand-operated facilities and, for automatic facilities, it reduces the room shielding thickness requirement.

Uncollimated sources can be used but it will often be found that the dose rate departs from the inverse square law, because of the presence of room scatter[34]. Since scattered radiation is much lower in energy than the primary beam, it affects the response of instruments that have a large change in response with energy, such as a thin-windowed sodium iodide scintillation detectors. The collimation angle should be chosen so that the largest detector expected is just completely irradiated at the minimum source to detector separation.

A3.5 Confirmation of photon energy dependence

The photon dose response is generally measured using ^{137}Cs (or ^{60}Co), and ^{241}Am for X and γ dose rate meters. For instruments that respond adequately at a level of approximately 10 μSv h^{-1}, a single source of 1 GBq used at a distance of 250 mm will be adequate for each photon energy. Care should be taken on wide ranging

instruments to ensure that all detectors are tested, especially on Geiger-Müller instruments that have a high dose rate and a low dose rate detector with sensitivities differing by factors of one hundred or one thousand.

For very low sensitivity (i.e. high dose rate) detectors, it may be necessary to use an X ray set generating an appropriate quality from the ISO narrow or wide series of reference filtered X radiations[14]. For other instruments which require a test of very low radiation energies, there is a limited range of options: there are some radionuclides of sufficiently low energy, such as ^{55}Fe (5.9 keV) and ^{129}I (27 keV), otherwise it will be necessary to use an X ray set generating filtered or fluorescent X ray qualities.

Appendix 4: Calibration of neutron dose rates

In general, neutron dose rate meters should be calibrated in a laboratory designed for the purpose in order to accommodate a wide range of dose rates, to minimise neutron scatter and to be able to perform the directional dependence measurements[35].

A4.1 Neutron calibration sources

Routine calibrations of neutron instruments are normally performed using radionuclide neutron sources of either ^{241}Am-Be or ^{252}Cf. A charged particle accelerator may also be used to produce the neutrons by bombarding appropriate neutron-producing targets. This latter approach can have advantages when performing tests for linearity and response to high dose rates but requires a very significant investment in facilities.

If accelerator-produced neutrons are used, their energy should be chosen to be appropriate for the workplace field in which the device will be used, for example, neutrons in the 2 to 3 MeV region produced using the reaction of low energy (100 to 200 keV) deuterons on a deuterium target. This consideration does not, however, apply for high dose rate (overload) testing, and the high dose rates which can be produced by the reaction of low energy (100 to 200 keV) deuterons on a tritium target provides one of the few means of laboratory production of sufficiently high dose rate fields leading to overload of neutron instruments.

Note that neutron sources are non-isotropic and it is important that during instrument testing they are mounted in the same orientation in which the source was calibrated.

A4.2 Characterisation of the calibration field

The recommended procedure is to calibrate instruments in low-scatter conditions, in accordance with the methods given by ISO[19-21]. The required dose response of the instrument is determined from its measured free-field fluence response and the recommended fluence-to-dose equivalent conversion coefficients[21,31].

In undertaking calibrations, the room and other scatter corrections are usually determined definitively for the given facility, source and instrument combination at appropriate source-to-instrument distances. Where practicable, two different procedures should be used to determine the corrections for scatter. These can be chosen from: analysis of measurements made as a function of distance[20]; the shadow cone technique[20]; or computational modelling of the scatter within the calibration room. Various methods are available for analysing measurements of the variation of detector readings with distance[20] and care should be taken that the analysis technique is appropriate for the construction of the particular calibration room. It is best when

performing a series of measurements to use the detector output of the instrument, using the pulse test output, both to minimise the uncertainties of a measurement and to avoid inherent inaccuracies arising from non-linearity in response of the instrument electronics.

While the above procedure is generally recommended for the calibration of neutron dose rate meters, it may not be feasible and could be unnecessarily expensive. Instead, it is possible to use a transfer instrument that has been calibrated at a primary or secondary laboratory. For this method a transfer instrument, of the same type as that to be tested, should be calibrated with an appropriate source of neutrons from either ^{241}Am-Be, ^{252}Cf, or an accelerator, at a standards laboratory following the ISO procedures[19-21]. It is then possible for the test laboratory to employ a similar source to test a monitoring instrument of the same type, using the calibrated transfer instrument to provide a direct calibration by substitution. The effects of scattering should still be minimised even though the scatter corrections are not determined explicitly.

A transfer instrument can also provide an excellent means of verifying scatter corrections determined by the techniques listed earlier.

A4.3 Instrument positioning

Instrument supports should be as light as possible, to minimise scattering, while being sufficiently rigid that they support any device safely and in a reproducible position. For neutron meters with spherical moderators, the normal orientation for calibration is with the electronics on the opposite side of the sphere to the source. Cylindrical devices should be positioned with the axis of the cylinder at right angles to a line from the source to the instrument.

A4.4 Linearity testing

If radionuclide sources are used, dose rates can be varied by changing the source-to-instrument distance, or by using a range of sources with different emission rates. With the former approach, care must be taken to ensure that the scatter corrections at the larger distances, where the corrections are significantly greater than at shorter distances, are known with sufficient accuracy that they do not distort the results.

If an accelerator is used as the source of neutrons, dose rates can easily be varied by altering the accelerator beam current. Care should, however, be taken that the fluence monitoring system is not adversely affected by different fluence rates.

A4.5 Confirmation of neutron energy dependence

In view of the wide range of neutron energies encountered in radiation protection (thermal to 20 MeV, or even higher around particle accelerators or where cosmic rays are a hazard), and the large variation with energy of the dose per unit fluence conversion coefficient, it has proved very difficult to devise radiation protection instruments that measure the required dosimetric quantity over the full energy range of interest. This, and the fact that workplace neutron spectra are seldom known with any degree of accuracy, makes it difficult for the QP to determine the most appropriate instrument and the correct field for calibration.

A measurement of the energy distribution of the workplace field, or at least an estimate based on the source of the neutrons and the degree of shielding, may be necessary before making these decisions. Conventional neutron meters based on a moderating sphere or cylinder are, however, more likely to over-respond by a significant amount in typical workplace fields than they are to under-read by a significant amount, so that deficiencies in the instrumentation only tend to be a serious problem where dose rates approach statutory limits.

A true test of the energy dependence of a neutron monitor, over the wide range of neutron energies that may be encountered, is outside the scope of most routine testing. The two radionuclide sources normally available, i.e. ^{241}Am-Be and ^{252}Cf, have broad energy range spectra with mean energies of 4.2 MeV and 2.1 MeV respectively. In terms of the energy range over which neutron meters are required to operate, these two energies are very close together and thus provide only a very limited test of the energy dependence.

Most testing laboratories have limited access to neutron sources and are rarely able to perform tests at two energies; therefore, without specialist facilities such as those found at a national standards institute, it is not generally possible to test the energy dependence of neutron dose rate meters and it is not a requirement of this guidance. In practice, it is therefore the responsibility of the instrument manufacturer to ensure that it has been assembled correctly and conforms to type. The QP responsible for later testing of the instrument may then rely on the type test results rather than testing its energy dependence in TBFU and Periodic Tests.

Appendix 5: Understanding and accounting for large area source non-uniformity

BS ISO 8769[18] defines acceptable limits for contamination source non-uniformities. All sources are, to a degree, non-uniform and therefore the emission rate directly under a contamination probe's window has an uncertainty that results in an additional uncertainty in the final calibration result for the probe. Any non-uniformity of the source under the probe will also couple with any non-uniformity in the probe itself to produce a different measured response depending on the probe orientation. The additional uncertainty caused by these effects can be limited using the techniques provided in this Appendix.

A5.1 Producing a map of emission rate from the source

Manufacturers check the uniformity of their sources for compliance with ISO standards but have not routinely provided the results with the sources. If data are available on the emission rate from a source, mapped on an area-by-area basis, it is possible to produce a better estimate of the emission rate directly under the detector. Depending on the equipment available, the mapping can be done in several ways.

A5.1.1 Multi-wire proportional counter

Complex multi-wire proportional counter systems allow the emissions to be traced back to their origin on the active surface of the source. However, there is a finite gap (several mm) between the source and the wires which leaves the system vulnerable to incorrectly registering emissions from neighbouring areas. These systems are expensive and require complex electronics and software; as such they are not normally the method of choice for contamination monitor calibration laboratories needing to determine their source uniformities.

A5.1.2 Image plates

Photostimulable phosphor plates (image plates) became available in the 1980s. The image plate can be placed in direct contact with the active surface of a source, reducing the effects of interference from neighbouring areas during mapping of emission rate. The image plate can be "read" with areal resolutions of better than 1 cm^2. Due to their high cost, image plates are suitable for use by source manufacturers but are not cost-effective for most source users.

A5.1.3 Mask, aperture and detector

A map of source emission rate can be produced easily using a mask arrangement. However, note this process is not designed to check source uniformity against the ISO specification but to provide information of sufficient precision for instrument testing. Figure 3 in Section 4.9.3.1 shows a possible arrangement where a suitable detector is placed on the mask immediately above the aperture. Suitable masked materials may be 2 mm of steel or 5 mm of aluminium for alpha and beta radiations and 3 mm of lead for X ray emitters up to 120 keV. Alternatively, a detector could be enclosed on the bottom and sides by a shield to eliminate interference from neighbouring areas but with an appropriate aperture in the bottom of the shield. Steel or aluminium can be used for the shielding.

For most beta and the more active alpha sources, the simplest detector to use is a nominal 2" pancake Geiger-Müller type; the detector should be used in virtual contact with the source. For photon emitters, sodium iodide detectors can be used for the mapping but greater shielding needs to be used to reduce interference from neighbouring areas. Assuming a 10 x 15 cm source, the simplest method to map the emission rate is to divide the active area into a 4 x 6 array, with each area (cell) being 2.5 cm square. Note this source size does not subdivide neatly into square areas of 10 cm^2 or 5 cm^2.

The net detector reading should be plotted as the detector is moved sequentially over each of the cells. The results may be presented as either a map of the net count rate or the net count rate normalised to the mean net count rate observed; see the examples provided in Figures 4 and 5 respectively. Inspection of the normalised values allows rapid visual identification of the most and least deviant cells of the source.

	65.8	**68.3**	**71.7**	**72.5**	**75.0**	**75.8**
	72.5	**79.2**	**85.0**	**82.5**	**78.3**	**89.2**
	78.3	**88.3**	**84.2**	**90.8**	**82.5**	**94.2**
^ 2.5 cm v	**79.2**	**94.2**	**97.5**	**100.0**	**106.7**	**88.3**

< > 2.5 cm

Mean observed net instrument reading = 83.3 s^{-1}

Figure 4: Net instrument readings observed during mapping with a mask

0.79	**0.82**	**0.86**	**0.87**	**0.90**	**0.91**
0.87	**0.95**	**1.02**	**0.99**	**0.94**	**1.07**
0.94	**1.06**	**1.01**	**1.09**	**0.99**	**1.13**
0.95	**1.13**	**1.17**	**1.20**	**1.28**	**1.06**

^
2.5 cm
v

< >
2.5 cm

Figure 5: Variation of instrument readings obtained using a mask, normalised to the mean net instrument reading obtained

A5.1.3.1 Effects of neighbouring cells in mapping

For the beta and alpha sources that are recommended in BS ISO 8769[18], it is only the cells that immediately surround the cell being measured that will have any measurable effect. For most practical purposes, because this is only a second-order correction, it can generally be ignored. However, it is relatively easy to measure how large the effect might be by making two additional mapping measurements at one of the corners of the source – one in the blank cell touching the corner cell at its side and one touching at its corner (see Figure 6).

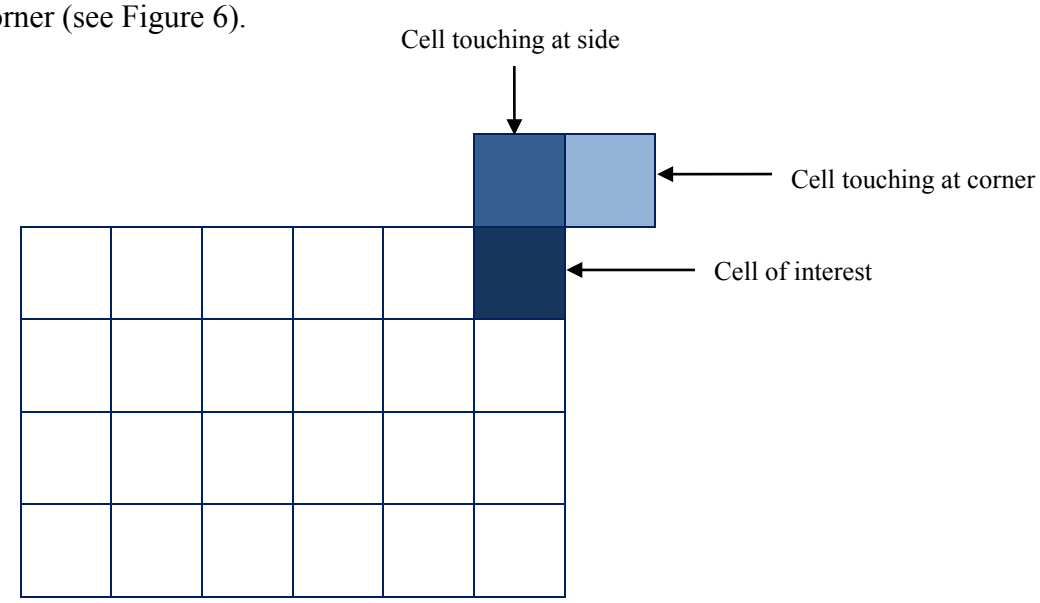

Figure 6: Effects of neighbouring cells

For photon sources, depending on the thickness of the uniformity probe shielding and the presence of a filter above the active layer, the effect of neighbouring cells may be somewhat larger and extend to greater distances as the photon energy increases. Further measurements extending beyond the edge of the calibration source will determine how large the effect might be and whether it can be ignored.

A5.2 Using a map of emission rate from the source

If information on the variation in emission rate over the active area of a source is available, it can be used to avoid making measurements over highly deviant regions of the source or to make an estimate of the effective source emission rate below the probe window. The optimum source area to use for instrument calibrations would be an area where the emission rate under the window is as uniform as possible and, if possible, where the emission rate in adjoining areas also has only limited variation from the area directly under the probe. From Figure 5 it can be seen that for a 49 cm^2 square probe (the side of the square is thus 7 cm and the probe will cover most of a 3 x 3 array of cells), the 9 cells in the top right corner of the source provide the most uniform region (however some cells within these are still deviant by 13 % from the mean emission rate).

The effective surface emission rate per unit area under the probe, SER_{eff}, can be defined as:

$$SER_{eff} = \frac{\sum_i E_N}{n} SER$$

where E_N is the net instrument reading from each cell i under the probe, normalised to the mean net instrument reading over all source cells mapped

n is the number of individual cells i under the probe

SER is the certified surface emission rate per unit area of the whole source.

Note that practical contamination monitoring probes may not fit perfectly on any map available and a degree of judgement will be required. Where the monitoring probe either covers a complete set of cells or, at least covers several and most of the perimeter set, then all the cells that the probe covers partially or completely should be used in the calculation. For example, if the values from all nine of the cells from the top right of the source in Figures 4 and 5 are used for the 49 cm^2 probe:

$$SER_{eff} = \frac{\sum_i E_N}{n} SER = \frac{8.89}{9} SER = 0.99 \; SER$$

Where there is only a very small overlap by the probe into some squares, it is probably better to use only the squares which are completely covered for the calculation. For example, if the probe were positioned centrally over the whole of the same source, the calculation should use only the central four cells:

$$SER_{eff} = \frac{\sum_i E_N}{n} \quad SER = \frac{4.11}{4} \quad SER = 1.03 \quad SER$$

If a more precise value of the instrument response, and hence the effective surface emission rate, is required, a more rigorous analysis can be carried out which accounts for the exact area of the source that is covered by the probe. Before embarking on such an analysis however, it should be noted that the example provided here for the probe positioned centrally over the source results in an effective instrument response (emissions) only 1 % different to that which would be obtained if the approximation technique described directly above were used.

The fractional area of each cell covered by the probe should be calculated, as shown in Figure 7.

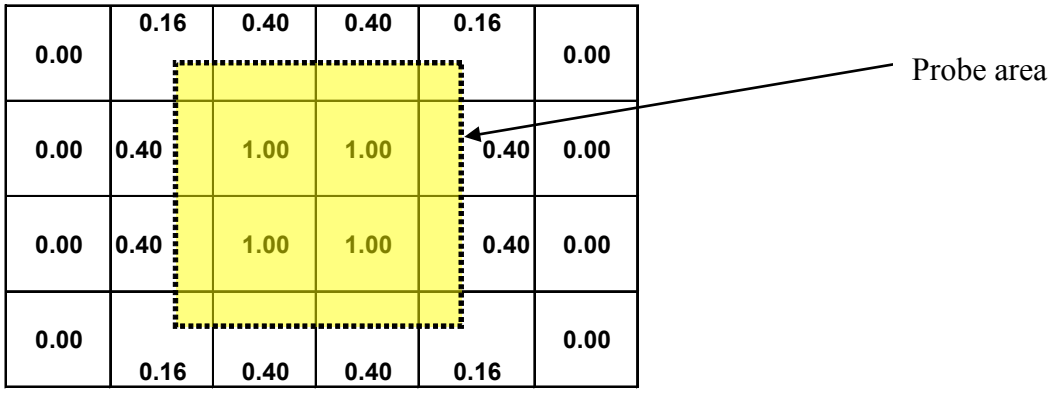

Figure 7: Fractions of each cell overlapped by the probe

The effective surface emission rate can then be calculated as follows:

$$SER_{eff} = \frac{\sum_i E_N \quad f_i}{\sum_i f_i} \quad SER$$

where f_i is the fraction of each cell i covered by the probe.

Therefore, for the pattern of cell coverage shown in Figure 7 and the normalised instrument readings shown in Figure 5:

$$SER_{eff} = \frac{\sum_i E_N \quad f_i}{\sum_i f_i} \quad SER = \frac{\sum_i (0.16 \text{ x } 0.82) + (0.40 \text{ x } 0.86) + (0.4 \text{ x } 0.87) + \quad ...}{7.84} \quad SER$$

$$SER_{eff} = \frac{7.99}{7.84} \quad SER = \quad 1.02 \quad SER$$

If this process of dealing with source uniformity had not been undertaken then the resulting average emission rate would simply have been equal to the SER.

The effective instrument response (emissions) and the effective 2π efficiency can be calculated from the effective surface emission rate as follows:

$$\text{Instrument Response (emissions)}_{eff} = \frac{(R - B)}{SER_{eff}}$$

$$2\pi \text{ efficiency}_{eff} = \frac{R - B}{SER_{eff} . A_P}$$

If we take a typical value of 10 particles per cm^2 per second for the SER of the source and an efficient probe that would be expected to generate 5 cps per cm^2 of probe area to such a source ((R-B)/cm^2). For the 49 cm^2 probe, that would give a total net count rate of approximately 250 cps (R-B). This would result in an effective instrument response (emissions) of 23 counts per second per particle per second per cm^2 of contamination using the uniformity information (rather than 25 if a uniform source had been assumed).

According to the equation provided in Section 4.9, the percentage 2π efficiency of the probe is the instrument response (emissions) divided by the probe area, in this case 49 cm^2, multiplied by 100, i.e. 47 %.

A5.3 Using a specific mask for each detector shape

An alternative approach to minimising the effect of source non-uniformity is to use a mask corresponding to the shape of each contamination monitor detector tested. This mask is then fitted to a large area (bigger than the source to be checked), thin windowed proportional counter; these detectors are intrinsically much more uniform than scintillation counters.

The uniformity of the proportional counter should be confirmed using a small area ^{14}C source for beta applications and a small area alpha source for alpha applications. The net count rate through the mask is then compared with the net count rate without the mask using the same source to detector separation, which should be minimal. The ratio of these numbers can be used to calculate the emission rate appropriate to the masked area, which can then be divided by the mask area to derive emission rate per unit area.

The disadvantage of this method is that it does not consider the source non-uniformity within the open mask area and this non-uniformity could interact with any contamination probe detector non-uniformity.

The proportional counter settings used are relatively unimportant as the result is the ratio of net count rates. However, as always, careful setting of the energy threshold and window is appropriate to minimise the uncertainty. For example, the background for an alpha measurement should be a fraction of a count per second and the efficiency for energetic beta emitters should approach 100 % for a counter with no protective grille.

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